CHAPTER 5

MACHINERY, EQUIPMENT, AND BUILDINGS: OPERATING COSTS

INTRODUCTION

Types of Costs Associated with Machinery, Equipment, and Buildings

The ownership and use of machinery, equipment, and buildings leads to a variety of costs. During a given production period, the owner of these assets incurs costs associated with (1) holding each asset over the period (including opportunity interest), (2) service reduction due to use and time, (3) changes in the implicit value of the assets' services, (4) maintenance, (5) service enhancement, and (6) the passage of time such as property tax and insurance. In Chapter 2 these costs were summarized using equation 2.25 as follows:

$$\begin{aligned} \textit{Total capital service cost} &= \textit{Opportunity cost} \\ &+ \textit{service reduction cost} \\ &+ \textit{change in price of the capital asset's service capacity} \\ &+ \textit{maintenance cost} \, (+ \textit{service enhancement cost}) \\ &+ \textit{other time costs}. \end{aligned}$$

Service enhancement costs are in parentheses because they are usually handled in conjunction with service reduction costs or the price change adjustments. Expenditures for maintenance and other time costs often involve the use of expendable inputs such as lubricants, parts, hired services, or operator labor. Thus they are often estimated in conjunction with other operating costs such as seed, fertilizer, and supplies. Costs associated with machinery, equipment, and buildings—such as opportunity interest and changes in service capacity or price—are often implicit and/or accrue over the life of the asset. Chapter 6 on durables addresses these costs, whereas this chapter specifically discusses the operating costs associated with machinery, equipment, and buildings.

Determining Input-Output Relationships for Machinery, Buildings, and Equipment

As discussed in Chapter 2, capital assets are one of the types of inputs used in the production of agricultural output. In assessing the cost of using alternative capital assets, it is useful to determine the output per unit of input in order to assess the productivity of alternative production systems. If the production system is of the Leontief type with fixed coefficients, then the output associated with a given asset is also fixed. In this case, the cost per unit of input can be used to compute the cost per unit of output using the constant technical coefficients. For example, if it is assumed that sweet corn production in central Washington uses 2.77 hours of tractor time per acre and the total cost per hour for using the tractor is computed to be $23.80

with yields per acre of 9.5 tons, the cost per ton for the tractor is [(2.77)(23.80)/(9.5)] = $6.94. This assumes that an hour of tractor time has the same productivity regardless of the tractor age or use per year. If the service output for the tractor varies with age or use, a more complicated procedure as discussed in Appendix 6A is needed. In analyzing operating costs associated with machinery, equipment, and buildings in this chapter, it will be assumed that it is reasonable to compute cumulative maintenance and other operating costs for these items based on total lifetime hours of use and then to convert these to a constant real cost per hour (day, year, etc.) of equally productive service, regardless of when that service is used within the economic life of the asset.

MACHINERY OPERATING COSTS

Methods to Estimate Machinery Operating Costs

There are two major methods of determining machinery operating expenses: producer surveys and direct estimation using equations based on survey information. Surveys of individual farms are generally used to calculate the costs and returns (CARs) of a specific commodity on a specific farm given the cropping mix and machinery set used on that farm. Where possible, surveys request producers to estimate machinery costs for an enterprise. Many producers, however, do not have adequate enterprise records to identify costs by enterprise. When producers do not have adequate records, it is necessary to allocate whole-farm costs to the individual enterprises. The allocation of whole-farm data to a specific enterprise is carried out in a variety of methods. These include percentage allocations by each producer, allocations based on machinery use on each enterprise, and allocations based on predetermined formulas. More discussion of these allocation issues is contained in Chapters 6 and 9.

Direct estimation of machinery operating costs utilizes previously estimated engineering equations. Costs are estimated using typical machinery hours, age, size, and type. This information is usually based on expert opinion, a consensus of selected producers, or a producer panel. Equations developed by agricultural engineers and economists are then used to calculate typical costs for production in a specific region taking into account typical machine usage and variations in the machinery complement used. The survey method and engineering method are not mutually exclusive and are sometimes combined. For example, surveys may be used to collect data on machinery use and size, which are then used with engineering equations to calculate costs. Engineering equations are also used with the survey method as a means of allocating whole- farm costs to specific enterprises. A disadvantage of engineering equations is that they do not fully account for unique farm characteristics such as the level of management. The level of management can impact machinery costs significantly, and can be important when making comparisons between a farm and regional averages.

The selection of which method or combination of methods to use in determining machinery repair or fuel use depends on a number of factors. Of major importance is the intended use of the cost estimates. The survey method is generally preferred when actual farm-level cost data are required. Actual farm-level cost data are often required when the estimates are used for policy analysis and program administration purposes. Policy analysis often examines the variability in returns and how different policies may impact different groups of farms by size and other variables. Policy analysis related to farm income issues is generally concerned with historical CARs that are best estimated with the survey method. In program administration and program evaluation, actual data from individual farms are often needed, thereby making the survey approach the most appropriate. However, even in the "Agricultural Resource Management Study" (formerly FCRS) conducted by the United States Department of Agriculture (USDA) Economic Research Service (ERS), total farm costs must be disaggregated by proportioning machinery costs to particular enterprises and, if needed, to particular field operations. This allocation is often accomplished using equations originally published by Bowers and Hunt. Another potential benefit of the survey method is that it permits farmers to compare their results against those of a group of farmers in a similar region.

Some uses of CAR estimates encompass situations where it is desirable to estimate machinery costs using engineering equations, such as when CARs are being projected for a specified farm organization on a typical or representative farm in a region. In other cases, such as for new machinery, survey information may not be available, making it necessary to use engineering equations. Engineering equations may be most appropriate for technology assessments which call for potential changes in machinery complements. Also, the equations are particularly useful for making quick comparisons between machinery alternatives for accomplishing a selected task.

In addition to the uses of the CAR estimates, there are a number of other factors one must consider in developing these estimates. Of importance are the resources which are available. The survey method has a disadvantage compared to the use of equations in that it can be expensive in both dollars and human resources required and the results obtained are tied to a point in time. Surveys are time consuming, making it difficult to have information available on a timely basis. Other problems such as sampling and nonsampling errors can impact the results of the survey approach. The engineering approach generally is inexpensive and does not require a large time commitment. A disadvantage of the engineering approach is that some of the engineering equations have not recently been updated, which may impact the accuracy of the results. However, because the equations often use machine list price as a parameter, the cost estimates can be adjusted for time by updating list price, fuel price, and so forth. There is and will continue to be an ongoing debate about which is more accurate and appropriate—survey or direct machinery cost estimation.

In comparing estimates from different sources, it is important to know which methods were used in calculating the costs. Direct comparisons between estimates based on the survey approach and the engineering approach are not possible. The most appropriate method to use will depend largely on the use of the estimates. Whatever method is used, information on how the costs are estimated must be provided to the potential user. For the survey method it is important to specify how, when, and where costs were collected and calculated. If whole-farm costs were allocated to a specific commodity, the allocation method should be reported. The collection of whole-farm data in the survey method is recommended even if allocations are not made on whole-farm costs. Whole-farm costs, at the very least, provide a useful check to verify commodity-specific costs. If engineering equations are used, details about the machinery complement and farm machinery use should be specified.

Chapter 5. Machinery, Equipment, and Buildings: Operating Costs

Using Surveys to Estimate Machinery Operating Costs

Surveying farmers to elicit their machinery operating costs by enterprise is a challenging task because most farmers do not maintain records for this purpose. Farmers usually only record income and expense information. To determine enterprise costs, either additional information necessary to allocate expenses to each enterprise of interest must be obtained, or machinery costs for each enterprise must be elicited directly.

The first method of surveying machinery costs assumes that costs of machinery operation are available at the farm level. Expenses for fuel, lubrication, repairs, and so forth for the entire unit can usually be obtained from farm account books, income tax returns, or other financial statements. In addition, information necessary to allocate the farm-level costs to the enterprises of interest must also be elicited. The additional information may either be objective data, such as acres of various crops and units of livestock, or various subjective factors, such as the operator's assessment of enterprise shares. If the producer does not have or remember detailed information on tillage operations associated with each activity, then estimation based on machine operations may be difficult. The use of a tableau similar to Figure 5.1 and /or the one discussed in detail in Chapter 9 may be helpful in the subjective allocation of machine time and machine costs.

The purpose of the top half of the tableau is to help the farm operator recall the acreages and machine operations associated with each enterprise. The operator may not be able to fill in all the information, but the more complete the information, the better will be the allocated estimates in the bottom half of the tableau. The top half may also be useful in determining the machine operations that are analyzed using engineering equations. Total farm expenses for fuel, lubrication, and repairs would then be entered in the whole-farm column. This data could come from available records and operator estimates of labor time involved in on-farm repairs. Repair expenses would then be allocated between tractors, combines, and implements (if possible), still in the whole-farm column. The purpose of allocating the repair expenses is to determine which types of equipment have the most repairs. Total fuel, lubrication, and repairs could then be allocated across enterprises. For example, on a Great Plains small grain farm, fuel costs for wheat and barley enterprises may each be estimated by the farm operator to be 50% of whole-farm expenses. Or, on an Idaho alfalfa and barley operation with 50% acreage in each crop, the allocation of repairs may be 65% to the alfalfa and 35% to the barley due to high repair costs for haying equipment. The column expense total could then be used in an enterprise-specific CAR.

An alternative to a subjective allocation by the producer, researcher, or farm management consultant is the use of a regression equation similar to

$$y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + e_t \qquad \textbf{(5.1)}$$

to estimate each enterprise share. The dependent variable y_t represents the total farm-level cost for an item such as fuel for the t^{th} farm in the sample, whereas the independent variables x_{1t} and x_{2t} represent different farm enterprises (usually measured in acres produced). For example, there may be different crops on a grain farm, or acres of crops and units of livestock on a combined crop/livestock farm. The coefficients of each variable are then interpreted as the respective cost of each unit. The intercept value $ß_0$ is defined to be the whole-farm level cost that is unallocated to each enterprise. Use of this method does require variation in costs and enterprise quantities among farms.

Figure 5.1 Allocation of Machine Costs for a Crop Producer

Item	Whole-Farm	Enterprise 1	Enterprise 2	Enterprise n
Total Acres				
Acres plowed				
Acres disced				
Acres harrowed				
Acres planted with planter				
Acres planted with drill				
Acres baled				
etc.				
Total fuel expense				
Total lubrication expense				
Total repair costs				
Repairs on tractors		X	X	X
Repairs on combines		X	X	X
Repairs on balers		X	X	X
Repairs on planters		X	X	X
etc.		X	X	X
TOTAL EXPENSE	Total Farm	Tot. Ent. 1	Tot. Ent. 2	Tot. Ent. n

Notes: (1) The top half of the table is completed first.
(2) The whole-farm column in the bottom half is completed next.
(3) The allocations across enterprises for total fuel, lubrication, and repairs is completed last. Boxes with X are not filled in.

The second method for obtaining machinery operating costs is to use a direct survey. However, these procedures are more complex. Past efforts have ranged from asking farmers to specify each component of cost directly to observing each farmer's actual usage of the resource involved. Asking farmers directly to report fuel costs per acre or repair costs per head of livestock can be efficient from the researcher's perspective because only minimal effort must be expended for data collection. However, the data obtained must be reviewed carefully to ensure that the farmers understand what is being asked of them and that the estimates obtained are accurate. To assist farmers with this process, various logs can be devised to aid and remind them of the data collection process. The underlying data to support estimation of the agricultural engineering equations described later were originally collected by this method. Observing farmers' direct usage of resources is far more time consuming but removes any errors associated with farmers' direct reporting of the costs. In either of these procedures, results and significance of the analysis are conditional on the sampling levels and methods employed.

Using Equations to Estimate Machinery Operating Costs for Crop Enterprises

Field operations to be performed and the set of machines to be used must be specified before costs can be estimated using engineering equations. Accurate specification of machinery costs using equations requires that the following steps be performed.

Farm Specification

Items required to identify the farm include (a) number of acres of each crop to be grown, and (b) machine operations on each crop, including time period (month or week) of execution. Machinery operating costs per acre typically do not vary much based on the size of machine as long as the implements and tractors are fairly well matched. However, the ownership costs can vary substantially depending on the size and annual use of equipment. Farms specializing on one crop may use farm equipment intensively for short periods of time, but may use the equipment relatively few hours per year causing ownership costs per acre to be high relative to diversified farms where machinery can be used on several crops over numerous time periods.

Machinery Selection

The set of machinery selected for a farm must be capable of performing all required tasks in a timely fashion. Also, it would be desirable to have a complement that can provide the required services for relatively low ownership costs. Developers of CAR estimates using machinery cost equations should always check the feasibility of the machinery complement being considered. This may involve something as straight forward as identifying the time period (month or week) where it appears that the greatest demands are being placed on the machinery complement and then determining the hours of use for each machinery item. Tractor hours are probably the most critical in terms of excess use. One tool for checking the feasibility of a machinery complement is found in Kletke and Sestak where a spreadsheet template (MACHSEL) is used for checking the feasibility of a complement and estimating the expected costs for a complement given any particular farm situation. The greatest difficulty with this kind of template and the engineering equations in general is the amount of information that must be provided about the farm, the farm organization, and the machinery to be used. (See also the last section of Chapter 6).

Engineering Equations for Estimating Machinery Repair Costs per Hour of Use

The American Society of Agricultural Engineers (ASAE) publishes procedures for estimating the costs to own and operate farm machinery. These procedures have been revised several times over their 40-year history. The latest procedures are given in the 1997 ASAE Standards[1]. The functional forms for cost estimation have changed over the years as well as the repair coefficients and length of life as machinery technology has improved. Rotz and Bowers give a good summary of the changes that have taken place in the engineering equations over time. These procedures have evolved from their start in the late 1920s and ’30s. In 1966 it was suggested that repair and maintenance costs be estimated as a function of machine age expressed as a percent of lifetime service hours.

$$AR = (RF1)(X)^{RF2} \tag{5.2}$$

where

AR	=	accumulated repair and maintenance as a percent of list price
X	=	accumulated use as a percent of lifetime hours
RF1, RF2	=	repair factors.

Note that AR is a percentage that must be multiplied by the list price to obtain total accumulated repairs and maintenance. In the late 1960s and early ’70s the equations were changed after several studies were completed on machinery repair costs. The following equation was developed from work by Bowers and Hunt.

$$TAR = (LP)(RP1)(RP2)(X)^{RP3} \tag{5.3}$$

where

TAR	=	total accumulated repairs and maintenance (dollars)
LP	=	list price (dollars)
X	=	accumulated use as a percentage of lifetime hours ($0 \le X \le 100$)
RP1	=	repairs over useful life as a proportion of list price ($RP1 \ge 0$)

[1] Standards: ASAE S495 (Dec 94), Uniform Terminology for Agricultural Machinery Management; ASAE Engineering Practice: ASAE EP496.2, Agricultural Machinery Management (Mar 94); ASAE Data: ASAE D497.3, Agricultural Machinery Management Data (Nov 96).

RP2, RP3 = paired constants providing shape to repair curve.

The coefficients RP2 and RP3 come in pairs which shape the distribution of repairs over the life of the machine. The coefficient RP1 is defined by $\frac{TAR^*}{LP}$ where TAR* is the value of equation 5.3 when the machine is at the end of its useful life. If h denotes accumulated hours of use and LIFE = total machine lifetime (hours), then $X = \frac{(h)(100)}{LIFE}$. When h = LIFE, then X = 100. Using this information we can define the relationship between RP2 and RP3 by evaluating 5.3 with h = LIFE. Specifically,

$$\begin{aligned} TAR^* &= (LP)\frac{(TAR^*)}{LP}(RP2)\,(100)^{RP3} \\ \Rightarrow 1 &= RP2(100)^{RP3} \\ \Rightarrow RP2 &= \left(\frac{1}{100}\right)^{RP3}. \end{aligned}$$

When working with the Bowers and Hunt repair equation, the RP2 and RP3 pairs reported in Table 5.1 must be used. The purpose of the pairs of coefficients is to allocate repairs over the life of the machine. The function of RP2 and RP3 is to shape the repair cost curve. The total expected repairs over the lifetime of the machine as a proportion of the initial list price is given by the Bowers and Hunt RP1 factor and so long as RP1 does not change, the total repairs over the life of the machine will not change no matter which set of RP2 and RP3 is used. As the RP3 factor (second column in Table 5.1) increases, repairs are moved towards the end of machine life. When the first pair of coefficients (.01 and 1.0) is used, repairs occur linearly over the life of the machine.

In 1977, a major change occurred in the equations. They were converted from three repair factors (RPi) to two repair factors (RFi) by expressing machine age in thousands of hours rather than as a percent of lifetime hours. In 1987, Rotz created an even more generic model that was adopted by the ASAE Standards Committee. This model is the standard in the latest ASAE publications. This accepted model is

$$C_{rm} = (RF1)(P)\left(\frac{h}{1{,}000}\right)^{RF2} \qquad \textbf{(5.4)}$$

where

C_{rm}	=	total accumulated repair and maintenance (dollars)
P	=	machine list price in current dollars
h	=	accumulated use (hours)
RF1, RF2	=	repair and maintenance factors.

The exponent (RF2) in equation 5.4 is the same as the exponent (RP3) in equation 5.3. The prices P and LP are also the same. The relationship between the other variables can be found by setting TAR = C_{rm} and using the fact that RP3 = RF2 and P = LP.

$$TAR = (LP)(RP1)(RP2)\left(\frac{(h)(100)}{LIFE}\right)^{RP3} = (LP)(RF1)\left(\frac{h}{1{,}000}\right)^{RP3} = C_{rm}\,.$$

By solving for RF1 as follows:

$$\begin{aligned}
(LP)(RP1)(RP2)\left(\frac{(h)(100)}{LIFE}\right)^{RP3} &= (LP)(RF1)\left(\frac{h}{1{,}000}\right)^{RP3} \\
\Rightarrow (RP1)(RP2)\left(\frac{100}{LIFE}\right)^{RP3} &= (RF1)\left(\frac{1}{1{,}000}\right)^{RP3} \\
\Rightarrow (RP1)(RP2)(100)^{RP3}\left(\frac{1{,}000}{LIFE}\right)^{RP3} &= RF1\,,
\end{aligned}$$

and, since $RP2(100)^{RP3} = 1$ it is determined that

$$(RP1)\left(\frac{1{,}000}{LIFE}\right)^{RP3} = RF1\,.$$

In summary, equation 5.4 (Rotz equation) is related to equation 5.3 (Bowers and Hunt equation) in the following manner.

Bowers and Hunt	Rotz
TAR	C_{rm}
LP	P
(RP1) $(1{,}000/LIFE)^{RP3}$	RF1
RP3	RF2

For those who want to use the Bowers and Hunt three-factor equations, the Rotz RF2 can be used to calculate the Bowers and Hunt RP2 as follows:

$$RP2\,(Bowers\ \&\ Hunt) = \frac{1}{100^{RP3(Bowers\ \&\ Hunt)}} = \frac{1}{100^{RF2(Rotz)}}\,. \qquad \textbf{(5.5)}$$

The Rotz equations do not allow users to control the way repair costs occur over the life of the machine as do the Bowers and Hunt equations. They also do not allow the user to specify what repair costs are expected to be over the life of the machine. Lifetime repairs as a proportion of list price can be obtained from the relationship $RP1 = RF1\left(\frac{LIFE}{1{,}000}\right)^{RF2}$. Because useful life is implicit in the Rotz equations, it is possible to obtain the RF1 values in Table 5.2 using information on useful life, lifetime repairs as a proportion of list price, and RF2. For the first tractor in Table 5.2 with lifetime repairs equal to 100% of list price, repairs as a portion of list price are

$$\begin{aligned} RF1 &= (1)\left(\frac{1{,}000}{12{,}000}\right)^{2} \\ &= .00069\overline{4} \\ &\approx .0007\,. \end{aligned}$$

TABLE 5.1 Paired Values for Repair and Maintenance Coefficients RP2 and RP3 where $RP2 = \frac{1}{100^{RP3}}$

RP2 (Bowers & Hunt)	RP3 (Bowers & Hunt) or RF2 (Rotz)
.0100000	1.0
.0063096	1.1
.0039811	1.2
.0025119	1.3
.0015849	1.4
.0010000	1.5
.0006310	1.6
.0002512	1.7
.0001585	1.9
.0001000	2.0
.0000631	2.1
.0000398	2.2
.0000251	2.3

In summary, the Rotz equations are easier to apply because only hours of use and list price are necessary to estimate the accumulated repairs. What is given up for this simplicity is the ability to vary total expected life (LIFE) and the amount of repairs expected over the life of the machine (Bowers & Hunt RP1). If users are willing to give up control of these parameters, then the Rotz equations are a useful simplification. However, because of the wide diversity in climate, variation in field conditions, and perhaps perceived differences in quality of workmanship in machine manufacture, the older Bowers and Hunt equations can be used because they will give identical results given the same assumptions while allowing more flexibility for users who want it.

In 1991, Rotz and Bowers revised the repair factors (RF1, RF2) for some types of machinery. Estimated life was increased for tractors, planting equipment, and self-propelled harvesting equipment and decreased for beet harvesting equipment and forage blowers. They also reduced the repair factors for selected machinery. These changes are included in the current ASAE Standards (ASAE D472.3 NOV 96, Table 3) and are summarized in Table 5.2.

The ASAE repair and maintenance procedure is designed to estimate all of the costs associated with repair and maintenance. These include all replacement parts, materials, shop expenses, and labor. Work done at a machinery dealership includes all of these costs. Repair work done on the farm should include a cost for the farmer's labor as well as a cost for maintaining a shop. Repair and maintenance costs are highly variable and unpredictable as to time of occurrence. Actual repair and maintenance costs vary widely with standard deviations likely exceeding the mean cost.

The ASAE equations are useful for predicting the average costs for repair and maintenance over the life of the machine. These equations have been used to estimate costs that occur during a relatively short period (one or two years), but it is not a recommended practice. Also, they should not be used to estimate repair and maintenance costs for machinery used beyond the estimated life of the machine. For machines used beyond their estimated hours of life, agricultural engineers recommend using the repair and maintenance cost estimated for the last year of expected life.

Converting Costs per Hour to Costs per Acre Using ASAE Standards

Field Performance

Field performance is needed to convert machinery costs per hour to a per acre or per unit basis. There are two methods for estimating performance. The first alternative is to obtain an estimate from the producer based on past experience. The second alternative is to use engineering equations to estimate field performance. For estimating costs of a specific field operation for a given producer, the first alternative is preferred. When producer estimates are not available, or when a typical or average measure is required, the second alternative can be used.

Estimating costs on a per acre basis requires knowledge of the effective field capacity of implements and self-propelled equipment. Effective field capacity is expressed as acres per hour for some machines (for example, plows and planters) or tons per acre for others (for example, balers and forage harvesters). The effective field capacity is estimated from the field speed, implement working width, field efficiency, and unit yield of the field for a given piece of machinery. Field speed is the average speed at which the functional work will be done in the field. For example, a farmer might average 4 mph plowing when the plow is actually in the soil. Implement working width is the measured width of the working portion of the machine. For example, for a planter it is the average row width times the number of rows. The ratio of effective field capacity to theoretical field capacity is the field efficiency of a machine. The field efficiency is expressed as a percent and is used to account for a number of factors that influence field operations, including failure to utilize the theoretical operating width of the machine, time lost turning, operator habits, field characteristics, and so forth. Travel to and from a field, repairs and maintenance, and daily service activities are not accounted for in the field efficiency coefficient.

Calculated area capacity is computed as follows:

$$C_a = \frac{(S)\,(W)\left(\frac{E_f}{100}\right)}{8.25} \tag{5.6}$$

where

C_a	=	acres per hour calculated capacity
S	=	implement speed in miles per hour
W	=	measured width of the implement in feet
E_f	=	field efficiency, the ratio of effective accomplishment compared to theoretical accomplishment, expressed in percent
8.25	=	43,560 (square feet per acre) divided by 5,280 (feet per mile) = width of acre 1 mile long.

Example: One of the machines used on the Ben and Bev Dairyman Farm is a 19N tandem disk. Ben estimates that he normally travels six miles per hour when disking. Table 5.2 indicates that a disk normally operates at about 80% efficiency because of turning, and in-field travel time. Given this information the expected acres planted per hour is

$$C_a = \frac{(6.0)(19.0)\left(\frac{80}{100}\right)}{8.25} = 11.0545 \ \mathit{acres/hour}\,.$$

The amount of product yield is used to estimate capacity for machinery such as balers that do not cover each square foot of the field. Calculated material capacity is computed as follows:

$$C_m = \frac{(S)(W)(Y)\left(\frac{E_f}{100}\right)}{8.25} \qquad \textbf{(5.7)}$$

TABLE 5.2 Field Efficiency, Field Speed, Estimated Life, Total Life Repair Cost, and Repair Factors for Selected Machinery

Machine	Field Efficiency Range %	Field Efficiency Typical %	Field Speed Range mph	Field Speed Typical mph	Field Speed Range km/h	Field Speed Typical km/h	Estimated Life h	Total Life R&M Cost % of List price	Repair Factors RF1	Repair Factors RF2
TRACTORS										
2 wheel drive & stationary							12,000	100	0.007	2.0
4 wheel drive & crawler							16,000	80	0.003	2.0
TILLAGE & PLANTING										
Moldboard plow	70-90	85	3.0-6.0	4.5	5.0-10.0	7.0	2,000	100	0.29	1.8
Heavy-duty disk	70-90	85	3.5-6.0	4.5	5.5-10.0	7.0	2,000	60	0.18	1.7
Tandem disk harrow	70-90	80	4.0-7.0	6.0	6.5-11.0	10.0	2,000	60	0.18	1.7
(Coulter) chisel plow	70-90	85	4.0-6.5	5.0	6.5-10.5	8.0	2,000	75	0.28	1.4
Field cultivator	70-90	85	5.0-8.0	7.0	8.0-13.0	11.0	2,000	70	0.27	1.4
Spring tooth harrow	70-90	85	5.0-8.0	7.0	8.0-13.0	11.0	2,000	70	0.27	1.4
Roller-packer	70-90	85	4.5-7.5	6.0	7.0-12.0	10.0	2,000	40	0.16	1.3
Mulcher-packer	70-90	80	4.0-7.0	5.0	6.5-11.0	8.0	2,000	40	0.16	1.3
Rotary hoe	70-85	80	8.0-14.0	12.0	13.-22.5	19.0	2,000	60	0.23	1.4
Row crop cultivator	70-90	80	3.0-7.0	5.0	5.0-11.0	8.0	2,000	80	0.17	2.2
Rotary tiller	70-90	85	1.0-4.5	3.0	2.0-7.0	5.0	1,500	80	0.36	2.0
Row crop planter	50-75	65	4.0-7.0	5.5	6.5-11.0	9.0	1,500	75	0.32	2.1
Grain drill	55-80	70	4.0-7.0	5.0	6.5-11.0	8.0	1,500	75	0.32	2.1
HARVESTING										
Corn picker sheller	60-75	65	2.0-4.0	2.5	3.0-6.5	4.0	2,000	70	0.14	2.3
Combine	60-75	65	2.0-5.0	3.0	3.0-6.5	5.0	2,000	60	0.12	2.3
Combine (SP)*	65-80	70	2.0-5.0	3.0	3.0-6.5	5.0	3,000	40	0.04	2.1
Mower	75-85	80	3.0-6.0	5.0	5.0-10.0	8.0	2,000	150	0.46	1.7
Mower (rotary)	75-90	80	5.0-12.0	7.0	8.0-19.0	11.0	2,000	175	0.44	2.0
Mower-conditioner	75-85	80	3.0-6.0	5.0	5.0-10.0	8.0	2,500	80	0.18	1.6
Mower-conditioner (rotary)	75-90	80	5.0-12.0	7.0	8.0-19.0	11.0	2,500	100	0.16	2.0
Windrower (SP)	70-85	80	3.0-8.0	5.0	5.0-13.0	8.0	3,000	55	0.06	2.0
Side delivery rake	70-90	80	4.0-8.0	6.0	6.5-13.0	10.0	2,500	60	0.17	1.4
Rectangular baler	60-85	75	2.5-6.0	4.0	4.0-10.0	6.5	2,000	80	0.23	1.8
Large rectangular baler	70-90	80	4.0-8.0	5.0	6.5-13.0	8.0	3,000	75	0.10	1.8
Large round baler	55-75	65	3.0-8.0	5.0	5.0-13.0	8.0	1,500	90	0.43	1.8
Forage harvester	60-85	70	1.5-5.0	3.0	2.5-8.0	5.0	2,500	65	0.15	1.6
Forage harvester (SP)	60-85	70	1.5-6.0	3.5	2.5-10.0	5.5	4,000	50	0.03	2.0
Sugar beet harvester	50-70	60	4.0-6.0	5.0	6.5-10.0	8.0	1,500	100	0.59	1.3
Potato harvester	55-70	60	1.5-4.0	2.5	2.5-6.5	4.0	2,500	70	0.19	1.4
Cotton picker (SP)	60-75	70	2.0-4.0	3.0	3.0-6.0	4.5	3,000	80	0.11	1.8
MISCELLANEOUS										
Fertilizer spreader	60-80	70	5.0-10.0	7.0	8.0-16.0	11.0	1,200	80	0.63	1.3
Boom-type sprayer	50-80	65	3.0-7.0	6.5	5.0-11.5	10.5	1,500	70	0.41	1.3
Air-carrier sprayer	55-70	60	2.0-5.0	3.0	3.0-8.0	5.0	2,000	60	0.20	1.6
Bean puller-windrower	70-90	80	4.0-7.0	5.0	6.5-11.5	8.0	2,000	60	0.20	1.6
Beet topper/stalk chopper	70-90	80	4.0-7.0	5.0	6.5-11.5	8.0	1,200	35	0.28	1.4
Forage blower							1,500	45	0.22	1.8
Forage wagon							2,000	50	0.16	1.6
Wagon							3,000	80	0.19	1.3

*SP indicates self-propelled machine.

where

C_m	=	tons per hour calculated capacity
S	=	implement speed in miles per hour
W	=	effective width of the implement in feet
Y	=	unit yield of the field in tons per acre
E_f	=	field efficiency, the ratio of effective accomplishment compared to theoretical accomplishment expressed as a percentage (so that dividing by 100 expresses this as a decimal)
8.25	=	43,560 (square feet per acre) divided by 5,280 (feet per mile) = width of acre 1 mile long.

Example: Ben and Bev typically bale alfalfa traveling four miles per hour. Their baler is only six feet wide but the swather width was 14 feet making the effective width of the baler 14 feet. The expected yield is four tons per acre. Table 5.2 indicates that balers are, on the average, 75% efficient. Given this information the tons/hour harvested will be

$$C_m = \frac{(4)(14)(4)\left(\frac{75}{100}\right)}{8.25} = 20.36 \ tons/hour \ .$$

Ranges and typical values for field speed and field efficiencies of machinery are given in Table 5.2. The data on field efficiency are almost always used in constructing cost estimates whereas the data on field speed provide a benchmark from which to compute individual estimates.

Repair and Maintenance

As discussed previously, total accumulated repair and maintenance costs can be estimated using the following ASAE formula due to Rotz and Bowers from equation 5.4 (here repeated as 5.8)

$$C_{rm\,t} = (RF1)(P_t)\left(\frac{h_t}{1{,}000}\right)^{RF2} \qquad \textbf{(5.8)}$$

where

$C_{rm\,t}$	=	total cumulative repair and maintenance cost at the end of year (hour) in dollars
P_t	=	machine initial list price in nominal dollars as of the end of the year (hour)
RF1	=	repair factor 1
RF2	=	repair factor 2

h_t = accumulated machine use in hours at the end of the t^{th} period.

For **repairs** and other costs estimated as a function of price, the **initial list price in nominal dollars at the end of the current period** is used. The initial list price is more stable than purchase price because of periodic dealer discounts and marketing incentives. It is assumed that the cumulative repair cost formula does not include any interest on the expense. For costs like **depreciation** (capital recovery), the expected **purchase price** after including typical discounts and incentives, rather than the list price, is used.

Example: Ben and Bev Dairyman own a 140-horsepower two-wheel (2WD) drive tractor and a 8-row (narrow) planter. These two machines will be used to illustrate estimating repair costs. For the purposes of this example we assume the tractor's initial list price is \$58,971. If there is no inflation, this would give a value in current nominal dollars of \$58,971. With inflation of 4.0% per year, the year-end value would be \$61,329.84. And we assume that Ben and Bev plan to use the tractor 300 hours per year and own the tractor for 20 years, a total of 6,000 hours of use. From Table 5.2, the repair cost factors are RF1 = .007 and RF2 = 2.0. The total repair costs over the period the tractor is owned are computed as follows:

$$C_{rm20}(tractor) = (.007)(58{,}971)\left(\frac{6{,}000}{1{,}000}\right)^{2.0} = \$14{,}860.69 \textit{ for the total over } 6{,}000 \textit{ hours}.$$

The total repair cost assuming 4% inflation for this year would be \$15,455.12. Figure 5.2 shows the total accumulated repairs for 2WD tractors with 500 hours of annual use as they are used. Repair cost is expressed as a percent of list price.

The planter has a list price of \$18,095 and will be used 75 hours per year for 15 years, a total of 1,125 hours. From Table 5.2, the repair factors are RF1 = .32 and RF2 = 2.1 so the cost is as follows:

$$C_{rm15}(planter) = (.32)(18{,}095)\left(\frac{1{,}125}{1{,}000}\right)^{2.1} = \$7{,}415.30 \textit{ for the total over } 1{,}125 \textit{ hours}.$$

Equation 5.8 gives total accumulated repair and maintenance costs for a machine that has been used h_t hours. The average cost per hour is calculated as

$$R/MCOST_h = \frac{C_{rm\,t}}{h_t} \qquad \textbf{(5.9)}$$

where

$R/MCOST_h$	=	average repair and maintenance cost per hour
h_t	=	accumulated use of the machine in hours at the end of year t
C_{rmt}	=	total cumulative repair and maintenance cost in dollars.

Contains Data for

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Figure 5.2. Total Accumulated Repairs as a Function of Hours of Use

> **Example:** The total accumulated repair and maintenance cost of $14,860.69 for the tractor over the 6,000 hours the tractor is expected to be owned gives an expected hourly tractor repair charge of $2.4767. This gives an annual expense, assuming 300 hours of use, equal to $743.03. With inflation of 4.0% this is an annual cost of $772.75 and an hourly cost of $2.58. Using the same procedure, the $7,415.30 planter repair cost over 1,125 hours

converts to an hourly expected repair charge of \$6.5914 and an annual charge of \$494.35. With inflation of 4% in current year this is an hourly charge of \$6.86.

Time Adjustments for Repair Costs

Equation 5.8 can be used to estimate the total repair costs over the time of machine ownership. It is normally expected that as a machine ages, annual repair costs will rise. Although dividing the total lifetime repair costs by the number of hours of use gives the average repair per hour, it does not take into account the relative greater importance of current repair costs relative to costs later in machine life. As long as annual costs are more or less stable throughout the life of the machine, as with fuel and lubricants, considering when those costs occur is not particularly important given their relatively low annual level as compared to other costs. However, because it is expected that most repairs will occur later in machine life, it is likely that repair costs are being overestimated when equations 5.8 and 5.9 are used directly.

An alternative procedure to assuming uniform repairs over the life of the machine is to estimate the expected annual or hourly repair expenditure for each year of machine ownership using equation 5.8 recursively. Because of the uncertain nature of repair costs, this is not a recommended procedure for estimating expected costs for a particular year. However, for determining an average repair cost reflecting differential time flows, this recursive procedure is appropriate. Based on equation 5.8, equation 5.10 permits estimating the expected repair cost in any particular year (or hour). Cumulative repairs at the beginning of the t^{th} period in beginning-of-period dollars are given by $C_{rm\,t-1} = (RF1)(P_{t-1})\left(\frac{h_{t-1}}{1,000}\right)^{RF2}$. Repairs at the end of the period are given by $C_{rm\,t} = (RF1)(P_t)\left(\frac{h_t}{1,000}\right)^{RF2}$. The difference between these two is the nominal repair cost in the t^{th} year. But if a real repair cost is being estimated, the same price must be used for each term as follows:

$$
\begin{aligned}
RC_t &= (RF1)(P_t)\left(\frac{h_t}{1,000}\right)^{RF2} - (RF1)(P_t)\left(\frac{h_{t-1}}{1,000}\right)^{RF2} \\
&= (P_t)(RF1)\left[\left(\frac{h_t}{1,000}\right)^{RF2} - \left(\frac{h_{t-1}}{1,000}\right)^{RF2}\right]
\end{aligned}
\qquad \textbf{(5.10)}
$$

where

RC_t	=	repair costs for year t in dollars
P_t	=	machine list price in nominal dollars at the end of year t
RF1	=	repair factor 1
RF2	=	repair factor 2
h_{t-1}	=	accumulated machine use at beginning of year (or hour) t in hours
h_t	=	accumulated machine use at end of year (or hour) t in hours.

The second term in the first line of 5.10 is the cost in current dollars of the cumulative repairs as of the end of the previous period. It is based on the list price of the machine at the end of the current period but with usage as of the beginning of the period. When P_t is constant over time, equation 5.10 can be written (using 5.8) as follows:

$$\begin{aligned} RC_t &= (RF1)(P_t)\left(\frac{h_t}{1,000}\right)^{RF2} - (RF1)(P_t)\left(\frac{h_{t-1}}{1,000}\right)^{RF2} \\ &= C_{rm\,t} - C_{rm\,t-1}. \end{aligned} \qquad \textbf{(5.10a)}$$

Example: Consider the 140-horsepower 2WD tractor owned by Ben and Bev Dairyman. The tractor's initial list price is $58,971. The repair and maintenance factors are RF1 = .007 and RF2 = 2.0. Previously the total repair cost for the 6,000 hours of useful life over 20 years were computed as $14,860.69. The cumulative repair costs assuming constant prices for the machine over a 19-year life at 300 hours per year are computed as follows:

$$C_{rm15}(tractor) = (.007)(58,971)\left(\frac{5,700}{1,000}\right)^{2.0} = \$13,411.77 \ \textit{for the total of} \ 5,700 \ \textit{hours}.$$

The costs for the twentieth year are then given by the difference between $14,860.69 and $13,411.77, or $1,448.92. Notice that because prices do not change we can simply subtract C_{rm19} from C_{rm20} to obtain the cost for year 20. If prices are changing, it is necessary to use the first line of equation 5.10 directly or multiply C_{rm19} by the inflation rate so that the same price can be factored out in equation 5.10. The costs for other years can be computed in a similar fashion, as in Table 5.3. One could also create a similar table with a row for each hour or month of machine use.

Table 5.3 Annualized Repair Cost for Example Tractor											
Tractor List price	58971										
Useful Life	20										
Annual Use	300										
Total Use	6000										
RF1	0.007										
RF2	2										
Real interest	0.05										
Annual Inflation (if applicable)	0.04										
Lifetime repairs (no inflation)	**14860.69**										
						Cummulated	Repair Cost	Cost in Year j	Cost in Year j	Annuity	
Year	Inflation rate	1+r	$1+p$	Hours	Hours	Cost	During	Disc. to	Disc. to	with Value	Discounted
	(actual)			Beg	End	at End of Year j	year j	Beg Year 1	End Year 1	of PV0	Annuity
1	0.000	1.050	1.000	0	300	37.151730	37.152	35.3826	37.151730	624.369383	594.637508
2	0.000	1.050	1.000	300	600	148.606920	111.455	101.0931429	106.147800	624.369383	566.321436
3	0.000	1.050	1.000	600	900	334.365570	185.759	160.4653061	168.488571	624.369383	539.353748
4	0.000	1.050	1.000	900	1200	594.427680	260.062	213.9537415	224.651429	624.369383	513.670237
5	0.000	1.050	1.000	1200	1500	928.793250	334.366	261.9841733	275.083382	624.369383	489.209749
6	0.000	1.050	1.000	1500	1800	1337.462280	408.669	304.9551223	320.202878	624.369383	465.914047
7	0.000	1.050	1.000	1800	2100	1820.434770	482.972	343.2395316	360.401508	624.369383	443.727664
8	0.000	1.050	1.000	2100	2400	2377.710720	557.276	377.1862985	396.045613	624.369383	422.597775
9	0.000	1.050	1.000	2400	2700	3009.290130	631.579	407.121719	427.477805	624.369383	402.474071
10	0.000	1.050	1.000	2700	3000	3715.173000	705.883	433.3508493	455.018392	624.369383	383.308639
11	0.000	1.050	1.000	3000	3300	4495.359330	780.186	456.1587888	478.966728	624.369383	365.055847
12	0.000	1.050	1.000	3300	3600	5349.849120	854.490	475.8118885	499.602483	624.369383	347.672235
13	0.000	1.050	1.000	3600	3900	6278.642370	928.793	492.5588908	517.186835	624.369383	331.116414
14	0.000	1.050	1.000	3900	4200	7281.739080	1003.097	506.632002	531.963602	624.369383	315.348966
15	0.000	1.050	1.000	4200	4500	8359.139250	1077.400	518.2479033	544.160298	624.369383	300.332349
16	0.000	1.050	1.000	4500	4800	9510.842880	1151.704	527.6087028	553.989138	624.369383	286.030808
17	0.000	1.050	1.000	4800	5100	10736.849970	1226.007	534.9028324	561.647974	624.369383	272.410294
18	0.000	1.050	1.000	5100	5400	12037.160520	1300.311	540.3058913	567.321186	624.369383	259.438375
19	0.000	1.050	1.000	5400	5700	13411.774530	1374.614	543.9814415	571.180514	624.369383	247.084167
20	0.000	1.050	1.000	5700	6000	14860.692000	1448.917	546.081756	573.385844	624.369383	235.318254
Sum							**14860.692**				
Present Value at Beginning of 1								**7781.022582**			**7781.02258**
Present Value at End of 1									8170.073711		
US0(r,20)								12.46221034			
Real Annuity with Value PV 0								**624.369383**			
Real Annuity with Value PV 1									655.5878521		

Because prices are assumed to be constant, the cost per year is just the difference in the cumulative costs. For example, the cost in year 4 is 594.43 - 334.37 = $260.06. As suggested in Chapter 2, these varying annual costs can be converted to a constant real annuity using capital budgeting procedures. The present value of this cost stream at the beginning of the first year is $7,781.02. The amortized average annual repair cost with this same present value can be determined using equation 5.11 (assuming a zero inflation rate).

$$ARC = \frac{\left(\sum_{j=1}^{n} \frac{RC_j}{(1+r)^j}\right)}{US_0(r,n)} = \frac{\left(\sum_{j=1}^{n} \frac{RC_j}{(1+r)^j}\right)}{\left(\frac{1 - \frac{1}{(1+r)^n}}{r}\right)} = \frac{r}{1-(1+r)^{-n}} \cdot \sum_{j=1}^{n} \frac{RC_j}{(1+r)^j} \qquad \textbf{(5.11)}$$

where

ARC	=	amortized average annual repair cost
r	=	real interest rate
n	=	years of life
RC_j	=	repair costs for year j as estimated using equation 5.10
$US_0(r,n)$	=	uniform series having interest rate r and n periods.

This annuity can also be obtained using the standard annuity functions available on business calculators or in spreadsheet programs (such as PMT in EXCEL). Those using calculators and spreadsheet functions to determine the present value of a series should be sure the calculations are performed assuming payments are made at the end of each period. For the example tractor these computations are presented explicitly in Table 5.3. For this example the annual repair amount is $624.37 as compared to $743.03 ($772.75 with inflation) using equation 5.8 directly and dividing the cost by total years of use. This is a payment at the end of each year that has the same present value as the various RC_t. This annual annuity amount can then be divided by the number of hours of use per year to estimate a repair and maintenance cost per hour. Because the annuity represents a payment at the end of year and repairs occur at various times during the year, these hourly expenses should be charged interest at a real rate from the time of occurrence to the end of the year. Using the real rate is appropriate because prices are assumed not to change during the year. Walker and Kletke indicate that for a cotton budget in southwest Oklahoma, changing the repair computation procedure from equations 5.8 and 5.9 to equations 5.11 and 5.9 for all machines can decrease the cost per acre from $19.53 to $17.98 per acre. As discussed in Appendix 2C, this annuity could be combined with the annuity constructed to represent the other costs of owning and using machinery to estimate an annual user cost of the capital asset (Burt 1992).

A concern with repair cost estimation is whether the repair cost equations generate costs in real or nominal terms. The preceding example assumes no inflation so that nominal and real values and interest rates are the same. If it is likely that the repair cost coefficients were estimated using survey data and were not adjusted, then the costs are likely in nominal terms. If the cost coefficients were determined by an “expert” using personal knowledge and information about the number of moving parts, and so forth, then the costs are likely in real terms. Although it is uncertain whether the repair costs are in real or nominal terms, it is usually assumed that they are in real terms at the point of estimation. This means that they are assumed to be in both real and nominal terms as of the end of the current year (period). If the list price is in nominal terms at the beginning of the production period, it should be adjusted to the end of the year using the current inflation rate before proceeding with repair cost estimation. Each of the costs in subsequent years can then be adjusted to the beginning of the first period to obtain a present value of total accumulated repair and maintenance costs. This present value can then be converted to an annuity for use in projecting average annual costs. The convention is to compute a real annuity having the same present value as the actual repair stream (real or nominal) and then adjust it using the appropriate inflation rate to obtain a nominal (or real) cost for each year.

It is usually assumed that repair costs occur and are paid when the machine is used. These costs will accumulate operating interest on repair and maintenance costs from the time the operation takes place until the end of the estimation period. The computed real annuity after inflation adjustments (or annual repair cost using equation 5.8) is in nominal terms at the end of the first period (year). Expenditures for repairs prior to the end of the period will accrue interest at a nominal rate from the point of occurrence to the termination point. But because inflation is assumed to occur during the production period, the actual expenditure at the earlier point has a lesser nominal value. Specifically, if a_e is a nominal payment at the end of the period, then the value at an expenditure point k months earlier is $a_{e-k} = a_e(1+p)^{\frac{-k}{12}}$ where p is the annual inflation rate. If this expenditure accrues interest at a nominal rate (i) the total cost including interest is given by

$$a_{e-k}\,(1+i)^{\frac{k}{12}} = a_e(1+p)^{\frac{-k}{12}}\,(1+i)^{\frac{k}{12}}\,.$$

To compute the interest component we subtract the expenditure without interest and then simplify,

$$\begin{aligned} ic(repairs) &= \left[a_e(1+p)^{\frac{-k}{12}}\right](1+i)^{\frac{k}{12}} - \left[a_e\,(1+p)^{\frac{-k}{12}}\right] \\ &= a_e(1+p)^{\frac{-k}{12}}\,(1+r)^{\frac{k}{12}}\,(1+p)^{\frac{k}{12}} - \left[a_e\,(1+p)^{\frac{-k}{12}}\right] \\ &= a_e\left((1+r)^{\frac{k}{12}} - (1+p)^{\frac{-k}{12}}\right) \\ &= a_e\,(1+p)^{\frac{-k}{12}}\left((1+i)^{\frac{k}{12}} - 1\right) \end{aligned} \qquad \textbf{(5.12)}$$

where ic(repairs) is the interest charge. This is the nominal interest on the nominal expenditure ($a_e\,(1+p)^{\frac{-k}{12}}$) for k months as given by equation 2.15.

Total repairs for a year in nominal dollars are usually allocated over the year by hours using total hours of use per year as in equation 5.9. This gives a cost per hour of use in end-of-year dollars. If hours of use per month are equal, this annual total cost can be divided into a nominal cost per month by finding a constant real cost per month that translates into total nominal expenditure. If real and nominal prices and costs are equal as of December 31 then a constant real cost, a_r, can be found using equation 5.13,

$$a_r(1+p)^{-\frac{11}{12}} + a_r(1+p)^{-\frac{10}{12}} + \cdots + a_r(1+p)^{-\frac{0}{12}} = a_r \sum_{j=1}^{12} (1+p)^{\frac{(j-12)}{12}} = Nom\ Exp \tag{5.13}$$

where the sum of nominal costs adds up to nominal expenditures (Nom Exp). Standard annuity functions and equation 5.14 can be used to find a_r,

$$\begin{aligned} a_r &= \frac{Nom\ Exp}{\sum_{j=1}^{12} (1+p)^{\frac{(j-12)}{12}}} = \frac{Nom\ Exp}{\sum_{j=1}^{12} (1+p_m)^{(j-12)}} \\ &= \frac{Nom\ Exp}{(1+p_m) \sum_{j=1}^{12} (1+p_m)^{(j-12-1)}} \\ &= \frac{1}{(1+p_m)} \left[\frac{Nom\ Exp}{US_0(p_m, 12)} \right] \end{aligned} \tag{5.14}$$

where p_m is the monthly inflation rate computed from equation 2.12. The last expression is obtained using equation 2B.7 and is the annuity having a present value of Nom Exp multiplied by $\left(\frac{1}{(1+p_m)} \right)$. This expression is thus easy to compute using standard functions such as PMT in Excel. By multiplying a_r by the appropriate monthly discount factor, a nominal cost per month for repairs is found. In such a nominal analysis with prices rising at the rate of inflation during the year, an hour of machine time will cost less at the beginning of the year than at the end. The nominal cost at the end of the year is the sum of the costs each hour or month.

If, as is probably more common, the number of hours per month varies over the year, a more complicated procedure is needed. In such a situation it is appropriate to find a constant real price per hour which, when adjusted for inflation and then multiplied by the number of hours per month and summed, is equal to total nominal expenditures. If the base period is the end of the twelfth month (December), we seek a constant real repair cost per hour R/M_h such that the following identity holds:

$$\sum_{j=1}^{12} R/M_h (1+p)^{\frac{j-12}{12}} h_j = Nom\ Exp \qquad \textbf{(5.15)}$$

where it is assumed that R/M_h is the real and nominal cost per hour at the end of December and h_j is hours of use in the j^{th} month (1=January and so forth). This equation can be solved for R/M_h as in equation 5.14 as follows:

$$\begin{aligned} R/M_h &= \frac{Nom\ Exp}{\sum_{j=1}^{12} h_j (1+p)^{\frac{(j-12)}{12}}} \\ &= \frac{Nom\ Exp}{\sum_{j=1}^{12} h_j (1+p_m)^{(j-12)}}. \end{aligned} \qquad \textbf{(5.16)}$$

Unlike equation 5.14, this cannot be simplified using standard annuity formulas due to the presence of h_j in the summation. This real value can then be adjusted for inflation to give a nominal cost per hour for each month. This nominal cost per hour is given by

$$R/M_h^n(j) = R/M_h (1+p_m)^{(j-12)} \qquad \textbf{(5.17)}$$

where the superscript n denotes the nominal cost and j denotes the j^{th} month.

Given the complexity of equations 5.14 and 5.16, an alternative is to assume constant nominal expenditures over the course of the year and use the average nominal cost per hour in year-end dollars as the cost for all hours during the year. This nominal cost per hour at the end of the year is also the real cost per hour since real and nominal values are equal at the end of the period. These "average" expenditures will, of course, sum to the total, but will overstate costs in the first part of the year.

> **Example:** Consider the example tractor with an assumed list price $58,971 and an annual inflation rate during the first year of 4.0%. This gives a year-end nominal list price of $61,329.84. The total accumulated repair and maintenance cost of $15,455.12 for the tractor over the 6,000 hours the tractor is expected to be owned gives an expected hourly tractor repair charge of $2.5785 which is reported in the cost per hour column in the exhibit below on the line labeled Nominal repair cost (equal use per month). This gives an annual expense, assuming 300 hours of use, equal to $772.756. The operating interest on this can be

calculated in a variety of different ways. Exhibit 5.1 below shows the computations for three alternative methods.

Exhibit 5.1 Alternative Methods to Calculate Interest on Repair Expenses

List price of tractor	58971
Useful life of tractor	20
Annual use	300
Total use	6000
RF1	0.007
RF2	2
Real interest rate	0.05
Inflation rate	0.04
Nominal interest rate	0.092
Monthly inflation rate	0.003274
Total repair expense over tractor's life (inflation = 4%)	15455.12
Cost/hour for repairs	**2.575853**
Cost/year for repairs	**772.756**
US0 (monthly inflation, 12)	11.7485

Item	Cost Per Hour	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 July	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	Per Month	Per Year
Hours of use per month		15.00	20.00	20.00	30.00	45.00	30.00	25.00	25.00	30.00	30.00	20.00	10.00	25.000	300.000
Real repair cost (equal use per month)	*2.62241*	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.56	65.560	
Nominal repair cost (equal use per month)	**2.57585**	63.25	63.45	63.66	63.87	64.08	64.29	64.50	64.71	64.92	65.13	65.35	65.56	64.396	**772.756**
Interest on line above		5.31	4.83	4.34	3.86	3.38	2.89	2.41	1.93	1.44	0.96	0.48	0.00		31.837
Nominal repair cost (average cost/hour & actual use)	**2.57585**	38.64	51.52	51.52	77.28	115.91	77.28	64.40	64.40	77.28	77.28	51.52	25.76	64.396	**772.756**
Interest on line above		3.25	3.92	3.52	4.67	6.11	3.48	2.41	1.92	1.72	1.14	0.38	0.00		32.497

The first line gives the actual hours of use each month. If this information were not available and it was instead assumed that hours of use per month were equal, equation 5.14 could be used to obtain a constant real payment that when converted to nominal terms would sum to the annual total expense of \$772.756. The computations are as follows:

$$a_r = \frac{1}{(1+p_m)}\left[\frac{Nom\ Exp}{US_0(p_m, 12)}\right] = \frac{1}{1.003274}\ \frac{772.756}{11.7485} = 65.5602\,.$$

This real payment appears in the per month column (and also the other columns) on the Real repair cost (equal use per month) line of Exhibit 5.1. The cost per hour in the real repair cost line is given by dividing the cost per month by the hours per month (\$65.5602/25) to obtain \$2.6224. This amount can then be adjusted to a nominal basis using the monthly adjustment formula analogous to equation 5.17. For example, the nominal cost in the eighth month [R/M^n (8)] is given by

$$R/M^n(8) = a^r(1+p_m)^{(8-12)} = (65.5602)\ (1.003274)^{-4} = 64.708\,.$$

The sum of these costs is \$772.756. Note that the cost per hour in effect rises over the year so that the cost of 25 hours in January is less than in December. Nominal interest on these expenses is \$31.837.

Rather than assuming that repairs are evenly spaced over the year, we can use the nominal cost per hour and multiply it by the hours of use each month. This will give the correct total repairs but will not allocate them in a way that accounts for rising prices during the year. To obtain the cost in the eighth month, take the number of hours in the eighth month (25) and multiply by the average cost per hour (\$2.5758) to obtain \$64.395. In this case, the costs in June and September are the same since the hours are the same. Nominal interest in this case is \$32.497.

The final and correct method is to construct a nominal cost per hour that is different for each month, accounts for different use per month, and sums to total nominal cost. This is done using equations 5.16 and 5.17. The denominator of equation 5.16 is constructed in the line of Exhibit 5.1 labeled Inflation-adjusted hours. The sum of this row is the denominator of 5.16. The real cost per hour is then given by

$$R/M_h = \frac{772.756}{294.589} = 2.62316\,.$$

This is reported in the cost/hour column and the real repair cost (actual use) line. The nominal cost per hour can be calculated for each month using 5.17. For the eighth month we obtain

$$\left[R/M_h^n\ (8)\right] h_8 = R/M_h (1 + p_m)^{(8-12)}\, h_8 = (2.62316)(1.003274)^{-4}(25) = 64.727\,.$$

The sum of these expenditures is also \$772.756. This set of monthly expenditures allows for differential hours and prices (due to inflation) each month. The interest on these expenditures is \$32.322. This is less than the interest expense computed using the average nominal cost per hour for every month and will always be so if inflation is positive.

Given the fact that interest on repair expenditures is usually a small proportion of total costs, the error created by charging interest on the average rather than the correct nominal value is probably not significant. In situations where computations are completely automated using a computer program, the cost of using the correct procedure is not great and could be used.

If it is assumed that all repair costs are estimated in nominal dollars, then equation 5.18 can be used to estimate a real amortized average annual repair cost. The primary difference is that each repair cost must be additionally deflated by the inflation rate to convert it to real dollars.

$$ARC = \frac{r}{1-(1+r)^{-n}} \cdot \sum_{j=1}^{n} \frac{RC_j}{(1+p_j)^j (1+r)^j} \qquad \textbf{(5.18)}$$

where

ARC	=	amortized average annual repair cost
p_j	=	inflation rate
r	=	real interest rate
n	=	years of life
RC_j	=	repair costs for year j as estimated using equation 5.10 assuming all costs are in nominal dollars.

Equation 5.18 is a general form of 5.11 and will yield the same answer when inflation is zero in every period. If we assume that inflation occurs each year at a 4.0% rate, then nominal machine repair cost will increase over time as in Table 5.4. The cost during year t is computed by subtracting from the accumulated cost at the end of year t [RC_t], the inflation-adjusted cost at the end of year t-1 [$(1+p)RC_{t-1}$]. This is made precise in equation 5.10b where p_t is the inflation rate in period t.

$$\begin{aligned} RC_t &= (RF1)(P_t)\left(\frac{h_t}{1{,}000}\right)^{RF2} - (RF1)(P_t)\left(\frac{h_{t-1}}{1{,}000}\right)^{RF2} \\ &= (RF1)(P_t)\left(\frac{h_t}{1{,}000}\right)^{RF2} - (RF1)(1+p_t)(P_{t-1})\left(\frac{h_{t-1}}{1{,}000}\right)^{RF2} \qquad \textbf{(5.10b)} \\ &= C_{rm\,t} - (1+p_t)C_{rm\,t-1}. \end{aligned}$$

Table 5.4 Annualized Repair Cost for Example Tractor with 4% Inflation Each Year											
Tractor List price	58971										
Useful Life	20										
Annual Use	300										
Total Use	6000										
RF1	0.007										
RF2	2										
Real interest	0.05										
Annual Inflation (if applicable)	0.04										
Lifetime repairs (no inflation)	**14860.69**										
						Cummulated	Repair Cost	Cost in Year j	Cost in Year j	Annuity	
Year	Inflation rate	1+r	$1+p$	Hours	Hours	Cost	During	Disc. to	Disc. to	with Value	Discounted
	(actual)			Beg	End	at End of Year j	year j	Beg Year 1	End Year 1	of PV0	Annuity
1	0.040	1.050	1.040	0	300	38.63779920	38.63780	35.3826	38.6377992	649.34416	594.63751
2	0.040	1.050	1.040	300	600	160.73324467	120.54993	101.0931429	110.393712	675.31792	566.32144
3	0.040	1.050	1.040	600	900	376.11579253	208.95322	160.4653061	175.2281143	702.33064	539.35375
4	0.040	1.050	1.040	900	1200	695.39630975	304.23589	213.9537415	233.6374857	730.42387	513.67024
5	0.040	1.050	1.040	1200	1500	1130.01900334	406.80684	261.9841733	286.0867172	759.64082	489.20975
6	0.040	1.050	1.040	1500	1800	1692.31645941	517.09670	304.9551223	333.0109936	790.02645	465.91405
7	0.040	1.050	1.040	1800	2100	2395.56796587	635.55885	343.2395316	374.8175685	821.62751	443.72766
8	0.040	1.050	1.040	2100	2400	3254.06130221	762.67062	377.1862985	411.8874379	854.49261	422.59777
9	0.040	1.050	1.040	2400	2700	4283.15818903	898.93443	407.121719	444.5769171	888.67232	402.47407
10	0.040	1.050	1.040	2700	3000	5499.36360073	1044.87908	433.3508493	473.2191275	924.21921	383.30864
11	0.040	1.050	1.040	3000	3300	6920.39915516	1201.06101	456.1587888	498.1253973	961.18798	365.05585
12	0.040	1.050	1.040	3300	3600	8565.28080560	1368.06568	475.8118885	519.5865823	999.6355	347.67224
13	0.040	1.050	1.040	3600	3900	10454.40107216	1546.50903	492.5588908	537.8743088	1039.6209	331.11641
14	0.040	1.050	1.040	3900	4200	12609.61606242	1737.03895	506.632002	553.2421462	1081.2058	315.34897
15	0.040	1.050	1.040	4200	4500	15054.33754392	1940.33684	518.2479033	565.9267104	1124.454	300.33235
16	0.040	1.050	1.040	4500	4800	17813.63034530	2157.11930	527.6087028	576.1487035	1169.4321	286.03081
17	0.040	1.050	1.040	4800	5100	20914.31537728	2388.13982	534.9028324	584.1138929	1216.2094	272.41029
18	0.040	1.050	1.040	5100	5400	24385.07857968	2634.19059	540.3058913	590.0140333	1264.8578	259.43837
19	0.040	1.050	1.040	5400	5700	28256.58611714	2896.10439	543.9814415	594.0277342	1315.4521	247.08417
20	0.040	1.050	1.040	5700	6000	32561.60616269	3174.75660	546.081756	596.3212775	1368.0702	235.31825
Sum							**25981.646**				
Present Value Beginning of 1								**7781.022582**			**7781.0226**
Present Value End of 1									8496.876659		
US0(r,20)								12.46221034			
Real Annuity PV 0								**624.369383**			
Real Annuity PV 1									681.8113662		

Equation 5.10b is equivalent to equations 5.10a and 5.10 when the inflation rate is zero. The cost in year 4 in Table 5.4 is obtained as 695.3963 - (1.04)(376.1158) = $304.2359. The present value of this entire income stream is $7,781.023, as before. The inflation-adjusted annuity value of $649.34 would be used as the cost for the first year. This could then be divided by the hours of use per year to get a cost per hour. This would then be charged interest at the nominal rate for the year from the time the hour of machine time was consumed until the end of the period.

If, as suggested in Chapter 2 and discussed in more detail in Chapters 6 and 10, nominal interest rates (including inflation) are assumed for the current year but real rates are used for periods other than the current one, equation 5.18 can be adjusted to reflect no inflation in list prices past the first year and then use real interest rates for future periods. If inflation occurs at a 4.0% rate during the production year but it is assumed there is no inflation thereafter, the results in Table 5.5 are obtained. As before, the present value of the cost stream is $7,781.023 with a real annuity value of $624.369. It is increased in the first year by 4.0% to $649.344 and remains the same thereafter. This can then be divided by annual hours of use to obtain a cost per hour. Interest on repair costs during the year occur at a real rate of interest.

The Task Force recommends that repair costs be estimated using either equations 5.8 and 5.9, which do not adjust for repair costs changing over time, or equations 5.18 and 5.9, which create a constant real annuity that reflects changing costs over time. If the latter set of equations (based on capital budgeting) are used to estimate repair costs, it is important these equations also be used for depreciation, taxes, and other costs that may vary substantially through time.

Repair Cost Estimates for Used Machines

It is expected that as machines age, repairs per hour will increase. This is also one of the characteristics of the repair cost equations. Thus repairs for a portion of machine life beginning at some point after the machine is new can be estimated by first determining repairs for the number of hours of use before acquisition and subtracting the results from the expected repairs for total machine life at the time it is retired by the second owner. Repair costs vary widely and the results are good only for use as expected repairs. As machines age, overhauls will be required and whether that occurs before or after a used machine is purchased can affect repair costs significantly.

Example: One of the tractors on the Midwest Dairy Farm was purchased used. A 1982 140-horsepower tractor was purchased in 1987 and had been used for 2,750 hours as of the beginning of 1992. The real list price of this tractor as of the end of 1991 is estimated to be $58,971 based on the list price of a similar new tractor in 1991. The Dairymans expect to use the tractor for 10 additional years for about 300 hours each year. When Ben and Bev sell the tractor, it will have a total of 5,750 hours (2,750 + (10)(300)) of use. We compute the cumulative cost of repairs over the first 10 years of use and then the cost of repairs over the second 10 years of use. This will give a higher cost per hour for the second ten years given the rising pattern of repair costs.

Table 5.5 Annualized Repair Cost for Example Tractor with 4% Inflation in Production Year and None Thereafter											
Tractor List price	58971										
Useful Life	20										
Annual Use	300										
Total Use	6000										
RF1	0.007										
RF2	2										
Real interest	0.05										
Annual Inflation (if applicable)	0.04										
Lifetime repairs (no inflation)	**14860.69**										
						Cummulated	Repair Cost	Cost in Year j	Cost in Year j	Annuity	
Year	Inflation rate	1+r	$1+p$	Hours	Hours	Cost	During	Disc. to	Disc. to	with Value	Discounted
	(actual)			Beg	End	at End of Year j	year j	Beg Year 1	End Year 1	of PV0	Annuity
1	0.040	1.050	1.040	0	300	38.63779920	38.63780	35.3826	38.6377992	649.34416	594.63751
2	0.000	1.050	1.000	300	600	154.55119680	115.91340	101.0931429	110.393712	649.34416	566.32144
3	0.000	1.050	1.000	600	900	347.74019280	193.18900	160.4653061	175.2281143	649.34416	539.35375
4	0.000	1.050	1.000	900	1200	618.20478720	270.46459	213.9537415	233.6374857	649.34416	513.67024
5	0.000	1.050	1.000	1200	1500	965.94498000	347.74019	261.9841733	286.0867172	649.34416	489.20975
6	0.000	1.050	1.000	1500	1800	1390.96077120	425.01579	304.9551223	333.0109936	649.34416	465.91405
7	0.000	1.050	1.000	1800	2100	1893.25216080	502.29139	343.2395316	374.8175685	649.34416	443.72766
8	0.000	1.050	1.000	2100	2400	2472.81914880	579.56699	377.1862985	411.8874379	649.34416	422.59777
9	0.000	1.050	1.000	2400	2700	3129.66173520	656.84259	407.121719	444.5769171	649.34416	402.47407
10	0.000	1.050	1.000	2700	3000	3863.77992000	734.11818	433.3508493	473.2191275	649.34416	383.30864
11	0.000	1.050	1.000	3000	3300	4675.17370320	811.39378	456.1587888	498.1253973	649.34416	365.05585
12	0.000	1.050	1.000	3300	3600	5563.84308480	888.66938	475.8118885	519.5865823	649.34416	347.67224
13	0.000	1.050	1.000	3600	3900	6529.78806480	965.94498	492.5588908	537.8743088	649.34416	331.11641
14	0.000	1.050	1.000	3900	4200	7573.00864320	1043.22058	506.632002	553.2421462	649.34416	315.34897
15	0.000	1.050	1.000	4200	4500	8693.50482000	1120.49618	518.2479033	565.9267104	649.34416	300.33235
16	0.000	1.050	1.000	4500	4800	9891.27659520	1197.77178	527.6087028	576.1487035	649.34416	286.03081
17	0.000	1.050	1.000	4800	5100	11166.32396880	1275.04737	534.9028324	584.1138929	649.34416	272.41029
18	0.000	1.050	1.000	5100	5400	12518.64694080	1352.32297	540.3058913	590.0140333	649.34416	259.43837
19	0.000	1.050	1.000	5400	5700	13948.24551120	1429.59857	543.9814415	594.0277342	649.34416	247.08417
20	0.000	1.050	1.000	5700	6000	15455.11968000	1506.87417	546.081756	596.3212775	649.34416	235.31825
Sum							**15455.11968**				
Present Value Beginning of 1								**7781.022582**			**7781.0226**
Present Value End of 1									8496.876659		
US0(r,20)								12.46221034			
Real Annuity PV 0								**624.369383**			
Real Annuity PV 1									681.8113662		

$$C_{rm10}(2{,}750\ \ hours) = (.007)(58{,}971)\left(\frac{2{,}750}{1{,}000}\right)^{2.0} = \$3{,}121.78$$

$$C_{rm20}(5{,}750\ \ hours) = (.007)(58{,}971)\left(\frac{5{,}750}{1{,}000}\right)^{2.0} = \$13{,}648.10\,.$$

The total repairs for hours 2,751 through 5,750 = $13,648.10 - $3,121.78 = $10,526.32. This gives a cost per hour for the remainder of the life of the machine of $3.51 (10,526.32/3,000). If there was 45 inflation during the current year, this would be revised to $14,194.02 - $3,246.65 = $10,947.37 or $3.649 per hour.

Fuel and Lubricants

Fuel and lube costs also can be estimated by survey or engineering equations. Survey procedures appropriate for general machinery operating costs also can be appropriate for fuel and lubricants. ASAE equations can be used to estimate the fuel efficiency or fuel consumption of the power unit. The fuel consumption is then multiplied by the fuel cost per unit to estimate fuel cost. Oil consumption can be estimated using engineering equations as well.

Engineering Equation Fuel Cost Estimates

The ASAE Standards give two methods for estimating fuel consumption. An average method can be used when an estimate of annual average fuel consumption for power units is all that is needed. This method is useful for predicting overall machinery costs for a given enterprise. When determining the costs for a specific operation (planting), fuel requirements should be based on the detailed formulas.

Average annual fuel consumption for a given power unit can be estimated as follows:

$$\begin{aligned} Gas_{gph} &= (.06)\ (PTO_{\max}) \\ Diesel_{gph} &= (.06)\ (PTO_{\max})\ (.73) \\ LPG_{gph} &= (.06)\ (PTO_{\max})\ (1.2) \end{aligned} \qquad \textbf{(5.19)}$$

where

Gas_{gph}	=	average gasoline consumption, gallons per hour
$Diesel_{gph}$	=	average diesel consumption, gallons per hour
LPG_{gph}	=	average liquefied petroleum consumption, gallons per hour
PTO_{max}	=	maximum PTO horsepower per hour.

The detailed method for estimating fuel consumption per hour is calculated as

$$F_{gph} = (HPR)\,(FM_{fuel}) \tag{5.20}$$

where

F_{gph}	=	fuel consumption in gallons per hour
HPR	=	equivalent PTO horsepower required
FM_{fuel}	=	fuel use multiplier for fuel type as defined below.

The fuel multipliers (FM) are given in equation 5.21.

$$\begin{aligned}
FM_{gas} &= (.54)\,\left(\frac{HPR}{HPM}\right) + (.62) - (.04)\,\sqrt{(697)\,\left(\frac{HPR}{HPM}\right)} \\
FM_{diesel} &= (.52)\,\left(\frac{HPR}{HPM}\right) + (.77) - (.04)\,\sqrt{(738)\,\left(\frac{HPR}{HPM}\right) + 173} \\
FM_{lpg} &= (.53)\,\left(\frac{HPR}{HPM}\right) + (.62) - (.04)\,\sqrt{(646)\,\frac{HPR}{HPM}}
\end{aligned} \tag{5.21}$$

where

FM_{gas}	=	fuel multiplier for gas engines, gallons per horsepower per hour
FM_{diesel}	=	fuel multiplier for diesel engines, gallons per horsepower per hour
FM_{lpg}	=	fuel multiplier for lpg engines, gallons per horsepower per hour
HPR	=	equivalent PTO horsepower required
HPM	=	maximum PTO horsepower.

Example: The more detailed way to estimate fuel consumption is with equations 5.20 and 5.21. The additional information required is the equivalent HPR required to pull the load for the implement in question. For this illustration it is assumed that the planter requires using 70 of the 140 horsepower available.

$$F_{gph}(140\ hp\ \ tractor) = (70)\ FM_{diesel}\ \text{ where}$$

$$FM_{diesel} = (.52)\,\left(\frac{70}{140}\right) + (.77) - (.04)\,\sqrt{(738)\,\left(\frac{70}{140}\right) + 173} = .09876,\ \text{so}$$

$$F_{gph}(140\ hp\ \ tractor) = (70)\ (0.09876) = 6.91\ gallons/hour\,.$$

Engineering Equation Lube Cost Estimates

A general estimate of oil consumption given by the ASAE Standards is .01 to .025 gallons per hour, depending on the volume of the engine crankcase. A detailed method relating oil consumption to engine size is given by the ASAE Standards as

$$\begin{aligned} Oil_{gas} &= (.00011)\ (HP) + (.00657) \\ Oil_{diesel} &= (.00021)\ (HP) + (.00573) \\ Oil_{lpg} &= (.00008)\ (HP) + (.00755) \end{aligned} \qquad \textbf{(5.22)}$$

where

Oil_{gas}	=	oil consumption for gas engines, gallons per hour
Oil_{diesel}	=	oil consumption for diesel engines, gallons per hour
Oil_{lpg}	=	oil consumption for lpg engines, gallons per hour
HP	=	rated engine horsepower.

Example: The estimated lube cost for the tractor is

$$Oil_{diesel}(140\ hp\ tractor) = (.00021)(140) + .00573 = .0351\ gallons/hour\ .$$

If filters are changed every other oil change, the total lube cost per hour approaches 15% of the total fuel cost.

Suggestions for Estimating Costs for Machines Not Listed in Tables

It is impossible for Table 5.2 to include all machines. When costs must be estimated for a machine not listed, and cost estimates are not otherwise available, it is suggested that parameters for a similar machine be used. Look through the tables for a machine having a similar number of moving parts, a similar power source, and a similar type of use. When estimating repairs, the key parameter in Table 5.2 is the ASAE total life repair cost. This coefficient determines the dollar amount of repairs over machine life. The other parameters only determine the distribution of those costs over machine life. For any machine, the equations provide an estimate of expected average repair costs over a number of hours of use and it is not likely that using coefficients for a similar machine will greatly over- or underestimate expected repair costs.

IRRIGATION OPERATING COSTS

There is not a consensus for how to estimate repair costs for irrigation equipment. The ASAE does not publish equations for estimating repair costs of irrigation equipment in the ASAE Standards, and extensive surveys have not been undertaken to estimate these costs.

One of the key elements in determining irrigation costs is application efficiency. For example, if the intent is to apply 12 inches of water using a surface system and if the application efficiency of flood application is 60%, it will be necessary to pump 20 inches of water to obtain the desired 12 inches. The application efficiency depends on the type of irrigation system, the type of soil, and weather conditions such as wind velocity and humidity.

Repair and Maintenance Cost Estimates

Jensen [1980] gives guidelines on estimating annual maintenance and repairs as a percent of initial cost. McGrann et al. [1986a, 1986b] use these same procedures. Table 5.6 gives these estimates for typical irrigation equipment. Thompson and Fischbach and later Selley use a different approach to estimating repair and maintenance costs for irrigation equipment. Table 5.7 gives the estimated repair and maintenance cost for power units and Table 5.8 presents delivery system repair and maintenance. As an example consider the following system.

Example Irrigation System

System Component	Initial Cost
Well (250 feet)	$11,850
Column Pipe (200 feet)	$8,016
Electric Switches	$1,701
Electric Service	$4,976
Land Shaping	$4,000
Pump Base	$1,433
Pump	$3,335
Electric Motor	$3,190
Sprinkler System	$30,000
Total	$68,501

Repair estimates using the McGrann et al. procedure are determined by applying coefficients from Table 5.6 to the expected investment given above. The McGrann et al. procedure provides annual estimates that do not depend on use. In this illustration the average of the upper and lower percent range in costs is used.

Repair Costs - McGrann et al. Procedure

Item	Percent	Annual Cost
Well	1	$118.50
Column Pipe	4	$320.64
Electric Switches	2	$34.02
Electric Service	0	0.00
Land Shaping	0	0.00
Pump Base	1	$14.33
Pump	6	$200.10
Electric Motor	2	$63.80
Sprinkler System	6.5	$1,950.00
Total Annual Repairs		$2,701.39

Repair cost estimates using the Selley procedure are given next. Repairs and maintenance are estimated on an hourly basis using the coefficients found in Table 5.7.

Repair Costs - Selley Procedure

Item	Rate	Hourly Cost
Power Unit	$.62/bhp/1,000 hr	$0.05
	20 hrs labor/1,000 hr @ $15/hr	$0.30
Delivery System	($0.08) (Pivot length/125)	$0.83
Total/Hour		$1.18

Assuming an annual use of 1,000 hours per year, the McGrann et al. procedure yields an estimate of $2.70 per hour, more than two times the estimate of Selley. Even if the lower end of the repair cost range from Table 5.6 is used, the McGrann et al. procedure yields an annual estimate of $2.05 per hour for the system, still significantly higher than the Selley method.

Energy Cost Estimates

McGrann et al. use the following procedure to estimate energy costs.

$$
\begin{aligned}
WHP &= (GPM)\,\frac{(FEET + [(PSI)\,(2.31)])}{3960} \\
TBHP &= \frac{WHP}{(PE)\,(GDE)} \\
PHRS &= \left(\frac{ACIN}{GPM}\right)(452.57) \\
TFU &= \frac{(2547)\,(PHRS)\,(TBHP)}{(BTU)\,(EE)} \\
FC &= (TFU)\,(FCOST)
\end{aligned}
\qquad \textbf{(5.23)}
$$

where

WHP = water horse power
GPM = gallons per minute pumped from well
FEET = static water depth

PSI = system pressure, in pounds per square inch
TBHP = brake horse power
PE = pump efficiency
GDE = gear drive efficiency (equals 1 for non-turbine)
PHRS = engineering estimate of annual use
ACIN = total acre inches pumped
TFU = annual fuel use
BTU = BTU's per unit of fuel
EE = engine efficiency
FC = total fuel cost
FCOST = cost per unit of fuel.

Table 5.9 gives the efficiency of irrigation components and Table 5.10 gives the BTU energy for the typical fuel alternatives. The energy cost estimates for the McGrann et al. procedure follow. The system is a low pressure center pivot system (800 gallons/minute, 35 PSI, 130 acres, 250′ well, 200′ column, 125′ lift, and 206′ head). The pump is driven by a 75 bhp electric motor and electricity is \$0.08 per KWH. Costs are estimated for one hour of use.

Energy Cost for Center Pivot Irrigation System
McGrann et al. Procedure

$$WHP = (800)\frac{(125+(35)(2.31))}{3{,}960} = 41.58$$

$$TBHP = \frac{41.58}{(.75)(1.0)} = 55.4$$

$$PHRS = \left(\frac{1.77}{800}\right)(452.57) = 1.00\ hour$$

$$TFU = \frac{(2{,}547)(1.00)(75)}{(3{,}410)(.87)} = 64.39\ KWH$$

$$FC = (64.39)(0.08) = \$5.15/hour\ .$$

The water horsepower required for the system is 41.58. This converts to a brake horsepower requirement of 64.39. Because this is less than the 75 brake horsepower engine specified, the engine size is adequate. Because the goal is to estimate costs for one hour, the acre inches, 1.77, are chosen so that the hours required equals 1.00. The hourly energy use is 64.39 KWH, which costs \$5.15 per hour.

Thompson and Fischbach and Selley estimate energy consumption for irrigating from the water horse power (WHP) requirement of the irrigation system. The WHP is estimated for all system types except center pivot as follows.

$$WHP = \frac{(Head)\ (GPM)}{3{,}960} \tag{5.24}$$

where

WHP	=	water horse power
Head	=	lift + (system pressure) (2.31)
GPM	=	gallons per minute system delivery.

For center pivots, WHP is estimated as

$$WHP = \frac{(Head)\ (GPM)}{3{,}960} + \frac{(.30)\ (PL)}{125} \tag{5.25}$$

where

WHP	=	water horse power
Head	=	lift + (system pressure) (2.31)
GPM	=	gallons per minute system delivery
PL	=	pivot length in feet.

Energy consumption is estimated as

$$EC = \frac{WHP}{EM} \tag{5.26}$$

where

EC	=	energy consumed per hour of operation, (gallons, kwh, or mcf depending on energy source)
WHP	=	water horse power
EM	=	energy use multiplier for energy type.

The energy use multipliers for each type are the following:

$$
\begin{aligned}
EM_{diesel} &= 12.5\\
EM_{electric} &= .885\\
EM_{lpg} &= 6.89\\
EM_{natural\ gas} &= 61.7\\
EM_{gasoline} &= 8.66
\end{aligned}
\qquad \textbf{(5.27)}
$$

where

EM_{diesel} = energy multiplier for diesel engines, gallons
$EM_{electric}$ = energy multiplier for electric motors, kwh
EM_{lpg} = energy multiplier for lpg engines, gallons
$EM_{natural\ gas}$ = energy multiplier for natural gas engines, mcf
$EM_{gasoline}$ = energy multiplier for gasoline engines, gallons.

Energy costs can be estimated by taking the energy consumption per hour and multiplying this by the per unit energy cost. This can then be annualized by taking the per hour cost and multiplying by the annual hours the irrigation system is used. Per acre costs can be calculated from this by dividing the annual cost by the number of acres irrigated by the irrigation system.

The per hour cost of irrigation is given by

$$E\$H = (EC)\ (FC) \qquad \textbf{(5.28)}$$

where

E$H = energy cost per hour of system use
EC = energy consumed per hour of operation
FC = fuel cost per unit, (gallon, kwh, mcf).

The annual cost of irrigation is computed as

$$AE\$ = (E\$H)\ (AH) \qquad \textbf{(5.29)}$$

where

AE$ = annual energy cost for system use

E\$H = energy cost per hour of system use
AH = annual hours of system use,

and per acre costs are given by

$$E\$A = \frac{AE\$}{Acres} \tag{5.30}$$

where

E\$A = annual energy cost per acre for system
AE\$ = annual energy cost for system use
Acres = acres of land irrigated with system.

The energy cost estimates for the Selley procedure follow. The system is a low pressure center pivot system (800 gallons/minute, 35 PSI, 130 acres, 250′ well, 200′ column, 125′ lift, and 206′ head). The pump is driven by a 75 bhp electric motor and electricity is \$0.08 per KWH. Costs are estimated for one hour of use.

Energy Cost for Center Pivot Irrigation System
Selley Procedure

$$WHP = \frac{(206)\ (800)}{3{,}960} + \frac{(.30)\ (1{,}290)}{125} = 44.71$$

$$EC = \frac{44.71}{.885} = 50.52\ KWH$$

$$E\$H = (50.52)\ (0.08) = \$4.04\ per\ hour\ .$$

The water horsepower required for the system is 44.71. Selley estimates energy use based on the water horsepower required. The water horsepower, 44.71, is divided by a fuel consumption multiplier, .885, to determine the units of energy consumed. The fuel consumed, 50.52 KWH costs \$0.08 per KWH and results in an energy cost of \$4.04 per hour of pump use.

Irrigation Lubricant Costs

McGrann et al. do not estimate a separate lubricant cost for the irrigation system. Selley estimates oil consumption as

$$OC = \frac{WHP}{OPU} + \frac{WHP}{OGD} \tag{5.31}$$

where

OC	=	oil consumed per hour of operation, gallons
WHP	=	water horse power
Hours	=	hours system is used
OPU	=	oil multiplier for power unit
OGD	=	oil multiplier for the gear drive.

Appropriate coefficients for OPU and OGD are

$$\begin{aligned} OPU_{diesel} &= 900 \\ OPU_{electric} &= 4{,}000 \\ OPU_{lpg} &= 800 \\ OPU_{natural\ gas} &= 800 \\ OPU_{gasoline} &= 800 \\ OGD &= 4{,}000 \end{aligned} \tag{5.32}$$

where

OPU_{diesel}	=	oil multiplier for diesel engines, gallons
$OPU_{electric}$	=	oil multiplier for electric motors, gallons
OPU_{lpg}	=	oil multiplier for lpg engines, gallons
$OPU_{natural\ gas}$	=	oil multiplier for natural gas engines, gallons
$OPU_{gasoline}$	=	oil multiplier for gasoline engines, gallons
OGD	=	oil multiplier for the gear drive, gallons.

Lubrication cost can be estimated similar to energy costs. The per hour costs are given by

$$L\$H = (OC)\,(O\$) \qquad \textbf{(5.33)}$$

where

L$H	=	lubrication costs per hour of system use
OC	=	oil consumed per hour of operation
O$	=	oil cost per gallon.

Annual lubrication costs for the system are computed by multiplying per hour costs (L$H) by annual hours of use (AH)

$$AL\$ = (L\$H)\,(AH)\,. \qquad \textbf{(5.34)}$$

Per acre costs are computed as

$$L\$A = \frac{AL\$}{Acres} \qquad \textbf{(5.35)}$$

where

L$A	=	lubrication costs per acre
AL$	=	annual lubrication cost for system use
Acres	=	acres of land irrigated by system.

The Selley procedure is used to estimate lubricant cost using the same example as previously. The required water horsepower, 44.71, is divided first by the power unit lubricant multiplier and then by the gear drive lubricant multiplier. Electric systems do not require a gear drive, thus, the second term of the equation, OC, is not used.

Lubricant Cost—Selley Procedure

$$\text{OC} = \frac{44.71}{4{,}000} = 0.011 \text{ gallons per hour}$$
$$\text{L\$H} = (0.011)\,(15) = \$0.165 \text{ per hour}\,.$$

The gallons of lubricant is estimated at .011 gallons per hour. If lubricants cost $15.00 per gallon, the lubricant cost is $0.165 for each hour the pump is used. The combined fuel and lubricant cost for the example is $4.21 ($4.04 + $0.17) for each hour the pump is used.

The two methods of estimating fuel and lubricant costs differ because McGrann et al. use the total brake horsepower (TBHP) to estimate energy consumption whereas Selley uses water horsepower (WHP). If 56.25 WHP were used in Selley's equations, or if 55.40 TBHP were used in McGrann et al.'s equations, the two methods would give very similar results.

TABLE 5.6 Annual Maintenance and Repairs for Irrigation Equipment

Component	Annual Maintenance and Repairs % of Initial Cost	Component	Annual Maintenance and Repairs % of Initial Cost
Wells and casings	.5 - 1.5	Pipe, asbestos - cement and PVC buried	.25 - .75
Pumping plant		Pipe, aluminum, gated, surface	1.5 - 2.5
Structure	.5 - 1.5	Pipe, steel, waterworks class, buried	.25 - .5
Pump, vertical turbine		Pipe, steel, coated and lined, buried	.25 - .5
Bowls	5 - 7	Pipe, steel, coated, buried	.5 - .7
Column, etc.	3 - 5	Pipe, steel, coated, surface	1.5 - 2.5
Pump, centrifugal	3 - 5	Pipe, steel galvanized, surface	1 - 2
Power transmission		Pipe, steel, coated and lined, surface	1 - 2
Gear head	5 - 7	Pipe, wood, buried	.75 - 1.25
V-belt	5 - 7	Pipe, aluminum, sprinkler use, surface	1.5 - 2.5
Flat belt, rubber and fabric	5 - 7	Pipe, reinforced plastic mortar, buried	.25 - .5
Flat belt, leather	5 - 7	Pipe, plastic, trickle, surface	1.5 - 2.5
Prime movers		Sprinkler heads	5 - 8
Electric motor	1.5 - 2.5	Trickle emitters	5 - 8
Diesel engine	5 - 8	Trickle filters	6 - 9
Gasoline engine, air cooled	6 - 9	Land grading	1.5 - 2.5
Gasoline engine, water cooled	5 - 8	Reservoirs	1 - 2
Propane engine	4 - 7	Mechanical move sprinklers	5 - 8
Open farm ditches	1 - 2	Continuously moving sprinklers	5 - 8
Concrete structures	.5 - 1		

Source: McGrann et al.

TABLE 5.7 Repair and Maintenance Costs of Power Units

	$/BHP/1,000 hrs	Hrs Labor/1,000 hrs
Diesel	5.00	20
Electric	.62	20
Propane, Natural Gas	2.40	40
Gasoline	3.15	40

Source: Selley.

TABLE 5.8 Delivery System Repair and Maintenance Cost Per Hour

System Type	$/hr
Pivot	.08 x Pivot length/125
Gated Pipe	$.02 \times \sqrt{acres}$
Side Roll	$.04 \times \sqrt{acres}$
Skid Tow	$.04 \times \sqrt{acres}$
Big Gun	$.08 \times \sqrt{acres}$
Reuse	$.02 \times \sqrt{acres}$

Source: Selley.

TABLE 5.9 Energy Use Efficiency of Irrigation Components

Item	Engine Efficiency (%)
Electrical Engine	
< 20 HP	91
> 20 HP	87
Diesel Engine	32
Natural Gas Engine	28
Gasoline Engine	
Air Cooled	26
Water Cooled	26
Propane Engine	28
	Pump Efficiency (%)
Centrifugal Pump	75
Turbine Pump Discharge Head	75
	Gear Drive Efficiency (%)
Gear Drive	
Right Angle	95.0
Direct	100.0
Belt, V-Belt	92.5
Flat Belt	87.5

TABLE 5.10 BTUs of Energy Per Unit of Fuel

Energy Source	BTU	Unit
Diesel	135,250	gallon
Electricity	3,410	KWH
Gasoline	124,100	gallon
LP Gas	92,140	gallon
Natural Gas	1,000,000	MCF

BUILDING AND EQUIPMENT OPERATING COSTS

Klonsky (1992) conducted a survey on data and methods used to develop enterprise budgets by land grant universities. Only 54% of those surveyed included building costs in enterprise budgets. In general, only buildings that could be charged entirely to a specific enterprise (for example, livestock buildings) were included. Buildings for equipment and/or shops were almost never included. Of those that included building costs, no data were collected on the repair of these buildings. Operating costs for buildings, including repairs and maintenance, could be obtained from general producer surveys, but would probably require specialized surveys designed to track such expenditures. Data on specialized buildings such as finishing units may be available from manufacturers, specialized farm record keeping systems, farm management consultants, or practicing agricultural engineers. Doane estimates repair and maintenance of buildings at 2-3% of original purchase or construction cost. Construction (purchase) costs for buildings might come from surveys, appraisal guides, or records of real estate transactions. More discussion of valuing the capital costs of buildings and equipment is contained in Chapter 6.

Operating costs for equipment, here defined as items other than farm machinery, are also difficult to estimate. Examples of items in this category are fencing, waterers, milk coolers, feed bins, feeding systems, etc. Often, these items are considered part of overhead and might not appear directly in the CAR estimate. Engineering estimates for repair and maintenance are usually specified as a percent per year of initial list price (Kletke). Where equipment is used by multiple enterprises, the costs must be allocated to the enterprise, and if the CAR estimate is being developed on a per head basis, the costs must be further allocated. The equipment items are so diverse that when they are estimated using surveys, they will generally be part of overhead. Whether building and equipment costs are estimated directly or included as part of overhead, CAR estimate developers should be certain that these costs are included.

INTEREST ON OPERATING COSTS (EXPENDABLE INPUTS)

All users of CAR estimates agree that interest should be included. Some view the interest as cost of funds used. Others view interest as an adjustment of all costs to a point in time. There is also some difference of opinion about whether the interest charge should be actual interest paid to lenders, full nominal opportunity interest, or real opportunity interest. The amount of interest charged should be based on the purpose of the CAR estimate, the amount of capital invested, and the appropriate rate of interest. Historical CAR estimates used for evaluating the financial position of operators may include only interest paid to lenders whereas CAR estimates used to develop and compare alternative government programs should include the full opportunity cost of capital. Cost and return estimates used for short-term cash flow planning may include interest expected to be paid to lenders whereas CAR estimates used for enterprise evaluations and comparisons should include the full opportunity cost of capital.

As discussed in Chapter 2, nominal interest should be charged on all operating costs incurred during the production period. In essence, the interest charge adjusts all costs to a single point in time. Costs and returns that occur at the CAR estimate termination date should not be charged interest. If costs occur at other than the CAR estimate termination date, interest should be charged to adjust these costs to the termination date.

Developing a framework for estimating interest requires that CAR estimate developers clearly state the use of the CAR estimate and the assumptions regarding interest charges.

Interest Rate Definitions

Financial interest: dollar amount paid to lenders for the use of funds.

Nominal opportunity interest rate: imputed interest charge reflecting nominal income foregone as a result of investing in the current enterprise. In the context of CAR estimates, the nominal opportunity cost is used to adjust a CAR estimate to the CAR termination date.

Real opportunity interest: imputed interest charge reflecting real income foregone as a result of investing in the current enterprise. In the context of CAR estimates, the real opportunity cost is used to adjust a CAR estimate from the current period to other periods and from other periods to each other.

Estimating Interest for Historical CAR Estimates

Historical CAR estimates can have two basic purposes: determining the actual cash costs of operating an enterprise or determining the economic costs of producing a unit of the enterprise. Historical CAR estimates are usually prepared by (a) the USDA Economic Research Service from surveys, and (b) universities that have records available from which to estimate the historical costs of production.

Actual cash operating interest is the financial interest charge paid to a lender. This would ideally be determined by survey: however, most operators do not have records that would permit precise allocation of interest charges to CAR estimates for a particular enterprise. In ERS cost of production estimates, whole-farm interest is allocated to the farm enterprises.

The historical CAR estimates prepared by ERS to estimate the economic costs of production use a combination of surveys and opportunity cost charges to estimate cash interest costs. The amount of operating capital invested in an enterprise is determined by survey and the charge for using that capital is an opportunity charge. The imputed cost of operating capital is based on the concept that rational producers expect the capital invested in variable production inputs to earn at least as much as funds invested in a savings account or some other interest-bearing financial instrument with similar risk. ERS currently uses a six-month Treasury bill rate as the opportunity interest charge (Morehart et al., Agricultural Handbook No. 671, 1992). More discussion of appropriate opportunity interest rates is contained in Chapter 2.

Estimating Interest for Projected CAR Estimates

Interest charges included in projected CAR estimates are determined by three identifiable components: the amount of money invested or expended, the rate of interest, and the length of time the money is tied up in the investment or expense. Estimating the amount of money on which interest must be paid requires knowledge of when expenditures are made and the termination date of the enterprise for a particular cost and return estimate. As stated in Chapter 2, **the Task Force recommends that projected CAR estimates establish the end of the production period as the reference point in time and that all expenditures and revenues be accumulated to the end of the production period**. Most CAR estimates are currently prepared using an opportunity interest rate because estimating cash interest payments to lenders requires knowledge of the operator's equity position.

Three alternative ways of determining the interest charge with advantages and difficulties for each are discussed here. Determining whether to use nominal or real interest rates further complicates the alternatives considered.

Alternative 1

A nominal rate of interest is used in this alternative. The approach assumes that the operator will borrow or charge at a nominal opportunity cost for all operating capital. The advantages of this rate are simplicity and understandability. Farm operators understand the charge and even if they do not borrow all the funds on which the charge is made, they understand the opportunity concept being used. A difficulty is specifying what the nominal rate should be. Alternatives include (a) a rate of interest that farm operators might pay for funds; (b) a rate of interest that farmers might receive for funds if an alternative investment had been chosen; and (c) a weighted average of the rate actually paid for funds on the amount actually borrowed and the rate the operator would receive on funds invested in other alternatives for funds not actually borrowed. The correct choice for most applications is the second one that reflects the opportunity cost of invested funds. The most common alternative nominal rate used, as discussed in Chapter 2, is the risk- and inflation-adjusted long-term real rate of interest.

Crop CAR estimates usually terminate at the point of first transfer of a salable product and this is normally the time at which interest charges terminate. With crop and livestock enterprises having multiple production periods (alfalfa and dairy cows for example), a time point must be chosen arbitrarily to terminate interest charges. This is usually the end of a calendar year or the end of a production cycle.

After the appropriate rate is chosen, the nominal interest charge for the j^{th} expense C_j (incurred n_j months from the terminal point of the estimation procedure) would be calculated as

$$(interest\ charge)_j = C_j(1+i)^{\frac{n_j}{12}} - C_j \tag{5.36}$$

where i is the annual nominal interest rate. The total of all interest charges can be computed as

$$interest\ charge = \sum_{j=1}^{m}\left(C_j(1+i)^{\frac{n_j}{12}} - C_j\right) \tag{5.37}$$

where m is the number of expenses on which interest is charged. In a similar fashion if an enterprise has returns that occur before the terminal point in the year, they should also be adjusted to this terminal point using the same nominal interest rate.

Alternative 2

This method computes interest based on the per period rate and the applicable proportion of the period. This means that if the interest rate is stated as an annual level, the rate for different subperiods will be the proportion of the year over which the cash flow is discounted, multiplied by the annual rate. Specifically, for an expense incurred n months before the terminal date of the enterprise, the approximate interest charge is

$$\begin{aligned}(interest\ charge)_j &\approx C_j[1+(\frac{n_j}{12})(i)] - C_j \\ &= C_j(\frac{n_j}{12})(i)\end{aligned} \tag{5.38}$$

where n_j is the number of months until the enterprise terminates. This method gives a higher interest charge than alternative 1 because the implied subperiod interest rate is higher than the actual rate computed in alternative 1.

This procedure can be modified for several conventions common in estimated CAR interest computations. One convention often used is to charge interest on expenditures for a fixed period, say six months, for all capital used. This implies that all n_j would be equal to the chosen proportion of the year. When it is assumed that all capital is invested for a certain length of time, say six months, the interest charge can be calculated by multiplying the total capital by 6/12 and multiplying the result by the annual interest rate. Although this approach may not be as precise as charging interest on each item for the length of time the capital is invested, it does provide a reasonable approximation for the cost of capital. Another convention sometimes used is to charge interest from the time of input use until a specified date other than termination date. For these situations n_j becomes the portion of a year elapsing from the time the input is purchased until the chosen date.

Alternative 3

A procedure using both real and nominal interest rates is to use the inflation rate to inflate the expense and income items to the chosen time period (Walker and Kletke) and then apply a real interest rate to these expenditures. As discussed in Appendix 2A, the appropriate adjustment for each income and expense item is

$$\begin{aligned}(\mathit{inflation\ adjusted\ cost})_j &= C_j^{\mathrm{p}} = C_j\,(1+\mathrm{p})^{n_j/12} \\ (\mathit{inflation\ adjusted\ revenue})_k &= R_k^{\mathrm{p}} = R_k\,(1+\mathrm{p})^{n_k/12}\end{aligned} \tag{5.39}$$

where

C_j	=	cost of input item j
C_j^{p}	=	inflation-adjusted end of year cost for item j
R_k	=	revenue from output k
R_k^{p}	=	inflation-adjusted end of year revenue for item k
p	=	rate of inflation
n_j , n_k	=	months of year the capital is invested.

After all costs and revenues are adjusted for inflation, the real cost of capital is computed using a real rate of interest. For each input the real rate of opportunity interest expense should be charged on each input for the period of time from purchase or use until termination of the CAR estimate, as in equation 5.36. Likewise, for each revenue item, there should be an opportunity interest income from the time the income is received until enterprise termination. This will then give

$$\begin{aligned}(\mathit{Real\ opportunity\ interest\ expense})_j &= C_j^{\mathrm{p}}\,(1+r)^{n_j/12} - C_j^{\mathrm{p}} \\ (\mathit{Real\ opportunity\ interest\ revenue})_k &= R_k^{\mathrm{p}}\,(1+r)^{n_k/12} - R_k^{\mathrm{p}}\,.\end{aligned} \tag{5.40}$$

These individual items can then be summed to obtain a net real opportunity interest expense as

$$\textit{Net real opportunity interest expense} = \sum_{j} \left(C_j^{p}\,(1 + r)^{n_j/12} - C_j^{p}\right) - \sum_{k} \left(R_k^{p}\,(1 + r)^{n_k/12} - R_k^{p}\right). \qquad \textbf{(5.41)}$$

For crops with a single production point, there will be no inflation or opportunity interest income on the revenue from production as long as sales come at the end of the period. For multiple production period crop and livestock enterprises, the value of production income must be adjusted for inflation and then receive a real rate of opportunity interest. The net of opportunity interest income and expense would be the net interest charge (income) for the CAR estimate. The CAR estimate termination point for multiple production period enterprises could be either the time of physical transfer of the last salable product, the end of the calendar year, or some other arbitrarily selected date.

Comparison of Alternatives

Variations of alternatives one and two are the most common ways of determining interest charges on CAR estimates. The rate of interest used is nominal and might be a weighted average of financial interest on borrowed capital and opportunity interest on operator-provided capital, or it might be opportunity interest only. Alternatives one and two use the nominal interest rate as a starting point, whereas alternative three requires knowledge of both inflation and real interest rates. Although both alternatives one and three are theoretically correct, alternative one is the most easily understood and is generally preferred by CAR estimate developers.

The distinct advantage of alternative three is having real interest determined separately from inflation. This permits the CAR estimate developer to not include inflation as an expense. There are, however, operational difficulties with alternative three. Although conceptually correct, there are numerous computations required. Also, accurate specification of inflation rates and real interest rates is required. Another concern is explaining the interest charge to farm operators and other CAR estimate users. Many users of CAR estimates understand the nominal rate of interest when it is related to what they pay for capital, particularly when interest is being paid to a lending institution. It is difficult to explain that the nominal rate is really composed of a real interest component and inflation and that only real interest should be considered. For more discussion of interest costs see the examples in Chapter 2, Tables 2.2-2.4.

CUSTOM OPERATIONS AND CUSTOM RATES

Definition

A custom operation is defined as the joint hiring of machinery, labor, and in some cases, purchases of materials to perform a production operation. Examples of crop operations are fertilizer application, land preparation, seeding, spraying, cultivating, harvesting, and hauling. Typical custom livestock operations are feed mixing, sheep shearing, and manure hauling and spreading. Custom operations could include all, none, or several of the tasks performed in the production of the product. Examples where all tasks are custom include custom crop farming or custom feedlots for finishing cattle. The charges for custom operations are commonly called custom rates.

Overview of Issues

Almost any task in production agriculture can be performed as a custom operation. Whether or not it is appropriate to use custom rates for CAR estimation depends on their purpose. When the intent is to determine the full cost of production, it may not be appropriate to use a custom operation unless it is typically performed by a custom operator and it is believed that the custom charge fully covers the operating and ownership costs of the custom operator. When the intent of the CAR estimate is to aid in financial decisions, or enterprise selection, it may be appropriate to use typical custom rates for any or all tasks. When CAR estimates are being prepared for individual farm decision makers, it is expected that the lowest cost alternative for acquiring a service would be used.

There are situations where local farmers do custom work for their neighbors, receiving some non-pecuniary benefits in lieu of, or in addition to, charging only what is necessary to cover their variable costs. Using these custom rates would underestimate actual production costs. If the custom operator is a neighboring farmer who does custom work after completing his own tasks, less timely operations could reduce output and profitability. If appropriate, yield adjustments should be made.

The size and type of farm operation determines the feasibility of using custom operators. Small crop, livestock, and dairy operations often cannot justify a large investment in agricultural machinery and equipment when both the money and the use of the capital items are limited. In these situations, it is more economical for small farm operators to rely on custom operations instead of owning the equipment and performing the activities themselves. At the same time, some small operators may have access to low cost equipment that would not be suitable for a larger operator.

Larger operations may often use custom operators for specialized tasks (for example, aerial spraying or seeding, soil fumigation, crop harvesting, or manure pit pumping and spreading) in the business. Agribusiness firms specializing in these operations are usually used by larger businesses. The custom operator may provide timeliness of operation, lower cost of investment, specialized skills, and/or unique equipment for the operation.

It is usually desirable for all materials used in enterprise production to be listed with the CAR estimate. However, when custom operators are used for labor-intensive harvesting operations, or when they provide specialized services, it may be difficult to divide the custom charge into costs of materials, labor, management, and custom operator profit. Where possible, custom charges should be divided into components, but when not feasible, it is permissible to include a custom charge for the complete custom activity. Listing of materials is particularly important for fertilizer, pesticides, and other cost items that may critically affect the production level or impact the social acceptability of the enterprise.

Current Procedures

Historical CAR estimates are obtained from surveys of farm operators. Because surveys include both operators who have and do not have custom work performed on their operations, the CAR estimate may include tasks that are part custom and part operator performed. Custom expenses in ERS CAR estimates are estimated from data reported in the Agricultural Resource Management Study (ARMS). Some states also perform surveys to determine costs of production.

Projected CAR estimates developed by land grant university extension and research staff, and others, are based on a composite of farm record program summaries, producer panels, cost estimation equations, and the expectations of expert panels. In projected CAR estimates, each operation will usually be performed either by the farm operator or a custom operator, but not a mixture of the two. If there are operations where custom operators are typical and where operators also perform the operation, multiple enterprise CAR estimates can be developed to reflect the different practices.

Custom rates per unit of production (planted acre, breeding animal, and hundredweight of products) are estimated by dividing the total custom expense by the number of planted acres, the number of breeding animals, or number of units of product. Where custom operations are performed by profit-oriented custom operators, custom rates can be used as a proxy for the operating and ownership costs of a specific operation or a series of operations in the enterprise.

Recommended Procedure

Custom operations should be appropriate for the intended use of the CAR estimate. **When full costs of production are being estimated, custom charges can be used when it is believed that the charge includes the full ownership and operating costs of the operation.** However, if the custom operator is not profit motivated and the resulting custom rate does not cover operating and ownership costs, then using the custom rate would underestimate the true cost of production. **Materials and labor requirements should be listed unless the custom operator cannot accurately divide the amount charged into components.** It is particularly important to list amounts and types of fertilizer, pesticides, and other inputs that may affect the production quantity or enterprise desirability.

On small farms, custom charges may be appropriate because operators can lower their costs by hiring tasks performed. (Developers of CAR estimates should be certain that the charge includes ownership and operating costs.) On large farms, custom operations may occur because custom operators can provide specialty services in a timely fashion less costly than the operator can perform the task(s).

When ownership and operating costs for a production practice are difficult to estimate directly, custom rates might be used as a proxy to estimate the costs for a specific production input, even though the operator might perform the task. This procedure should be avoided if at all possible, because the actual costs to the operator might be either higher or lower than the custom charge.

OTHER COMMODITY-SPECIFIC COSTS

There are numerous costs which must be dealt with on an item-by-item basis. These costs can be divided into several groups having similar characteristics. Following is a discussion of the groups and some of the characteristics of costs in each group. This section concludes with a discussion of examples for each cost group.

The purpose of developing generalized CAR estimates is to provide information that will be useful for the many alternative uses made of CAR estimates. It is essential that costs reflect the actual and full costs of performing a task or providing a service. With this in mind, costs included in this section should include both direct costs to the producer as well as reductions in prices received because of involuntary checkoffs or marketing charges. Cost and return estimates should provide sufficient information so that either net returns to producers or economic costs of production can be estimated.

General Guidelines

- If possible, cost items should not be subtracted from the commodity price. For example, transportation costs should not be subtracted from the price of the product, but included as a cost. The reported product price should be the price before any costs are deducted.

- If it is not possible to have the cost items separated from the commodity price, the CAR estimate must indicate clearly which cost items have been included in the price.

- Where possible, costs should be separated into basic components. For example, production costs should be separated from marketing costs.

- Costs should be specified so that users can observe whether they vary by the amount of production or are set for the unit of production. For example, hauling charges for wheat should be so much per bushel times the number of bushels produced rather than entered as a total hauling cost per acre. If the cost of an item varies with the number purchased or marketed (such as quantity discounts or premiums) the price and quantity assumed for the estimate should be reported.

- Costs reported should include both ownership and operating components. When services are purchased, costs should include the full cost of providing the service.

- The cost of an input should be the cost expected at the time of application or use and not necessarily at the time of purchase. If a producer typically purchases an input prior to its use, this purchase cost should be adjusted to the time of use to make it compatible with other inputs applied at the same time. All the costs of a given production operation (such as machine time, labor, and seed for planting) should then be adjusted to the end of the production period.

- Costs for inputs providing benefits for more than one production cycle should have their costs spread over the duration of the benefit. Further discussion of how to do this is contained in Chapter 10: Allocating Preproductive Costs for Multiyear Enterprises.

- Costs should reflect the most common practices in a region, and CAR estimates prepared with other assumptions should be identified clearly.

- If costs are not evenly distributed between systems, multiple CAR estimates should be prepared (irrigation vs. nonirrigation, reduced vs. no-till).

- Footnotes to the CAR estimate, or accompanying text, should provide sufficient information for readers to understand assumptions and procedures for estimating costs.

Costs for Operations Which Can Be Completed Either On-Farm or Commercially

Examples of this type of cost include storage, drying, ginning, sheep shearing, and transportation. Many producers do not have the equipment or facilities to perform these tasks and, for these operations, the only alternative is to have them performed commercially. When CAR estimates are prepared for producers having the capability of performing these operations, all costs (ownership and operating) related to these activities should be included. Additionally, for costs such as storage, the expected shrinkage and spoilage in the amount of product to be sold should be specified.

Costs for Services or Commodity-Specific Supplies

Examples include marketing charges and cartons, bags, tags, and so forth. Products sold frequently during the year often require employing an agent to assist in marketing the product. Commissions paid to the agent are typically commodity specific. The marketing of many fruit or vegetable products requires the purchase of bags or cartons for packing the product. These costs should be specified so that the user of the CAR estimate has the most information possible.

Costs Required for Obtaining the Rights to Produce or Sell Farm Products

Examples include quotas, permits, involuntary checkoffs, certifying crops as organic, and marketing order assessments. These costs are typically set by law or agreements among producers. Some costs may be based on the production unit (acre or head), others on the units produced (bushels or cwt.). Whatever the charge, the impact on CARs should be reflected as a cost item rather than a reduction in sales price. A more complete discussion is contained in Chapter 9.

Crop Insurance

When a crop insurance coverage level is chosen, a minimum level of production is guaranteed. This guaranteed minimum production will reduce income variability and cause the expected production from the enterprise to have an average somewhat greater than the guaranteed crop insurance minimum. Over time and in aggregate, it is expected that the proceeds from crop insurance will equal the cost of crop insurance less the cost of managing the crop insurance program. Thus, over time, one would expect the net proceeds from crop insurance to be slightly less than the costs unless the program is being subsidized. Any time crop insurance is included in a CAR estimate, the CAR estimate developer should ensure that the cost of crop insurance exceeds the expected proceeds unless the program is being subsidized.

How crop insurance is incorporated into CAR estimates depends on the use of the CAR estimate and what is typical in the area. Whenever crop insurance is included as a cost, care should be exercised to ensure that the income level reflects the expected reduction in variability (and resulting increase in average production). Whether crop insurance proceeds are handled as an entry separate from production is up to the developer. But, information provided with the CAR estimate must be explicit so that CAR estimate users are informed adequately. Also, coverage level assumptions and any other information needed to identify costs and benefits accurately should be stated. See also the subsection in Chapter 3 entitled Commodity Loss or Damage Insurance.

Selected Commodity-Specific Costs

Drying Costs

- Do not net from sales price.

- Use commercially available rate per unit of production or estimate all costs (ownership and operating) for on-farm drying.

- Commercial rates will typically be on a per unit produced basis. In some cases the per unit charge may vary directly with the amount of moisture removed.

- On-farm drying costs require estimating ownership costs as well as determining fuel usage and labor requirements for drying the typical amount of production for an acre.

- Assumptions and procedures used for estimating costs should be summarized in a footnote or accompanying text.

Storage Costs

- Storage costs are not expected in most situations since CAR estimates terminate at the point of first physical transfer of a salable product. Thus, storage costs are expected only if storage is required to assemble a salable product.

- If it is necessary to store crops, either commercially available off-farm storage or on-farm storage may be used.

- Storage costs should only be included until the CAR estimate is terminated (point of first transfer).

- Off-farm storage will normally be charged at a per unit of production per unit of time (cents/bushel/month) rate.

- On-farm storage will require estimating ownership and operating costs for the storage facility. Operating costs should include labor and any fumigants or other chemicals typically used in grain storage.

- Shrinkage and spoilage are associated with on-farm storage. The loss of production units (bushels) due to shrinkage and/or spoilage depends on time of storage. For commodities stored, the amount of production loss due to shrinkage and spoilage should be stated and subtracted from the stated field yield so that the amount of product sold can be specified accurately.

- Assumptions used for estimating storage costs should be summarized in a footnote or accompanying text.

- Storage costs for inputs purchased preseason should be included if significant.

Transportation Costs

- Because CAR estimates typically terminate at the point of first product transfer, transportation costs may or may not be necessary. For products sold in the field or livestock sold at the farm gate, no transportation charges should be included. For products and livestock delivered to a central point, transportation charges to that point should be included.

- Transportation can be performed either by the operator or as a custom operation.

- Custom transportation is often provided with custom grain harvesting operations. Usually, the transportation charge is made separately from the harvesting charge. The cost will depend on the amount of production and the distance hauled.

- Commercial truckers are often used to transport livestock. Expected rates should be multiplied by weight to determine the expected hauling charge.

- For producers providing their own transportation, both ownership and operating costs must be included. Fuel, lubricants, repairs, and labor costs associated with transportation must be included to estimate the economic costs of production.

- Assumptions for estimating transportation costs should be summarized in a footnote or accompanying text.

- When commodity prices assume that transportation is provided by the buyer and it is impossible to separate the cost component, the price should be clearly identified as a field or farm gate price.

Ginning Costs

- The value of seed produced should not be used to offset ginning charges. As a result, it is necessary to include the sale of seed in the list of products produced.

- Normally, ginning costs will be available as a cost per unit of product. The cost per acre can be estimated by multiplying the ginning cost per unit by the number of units produced per acre.

- Assumptions for estimating ginning costs should be summarized in a footnote or accompanying text.

- Ginning costs are often charged on the basis of seed cotton (lint, seed, burrs, trash) prior to ginning. When this is done, one must factor in the ratio of seed cotton to lint in order to include ginning costs accurately.

Shearing Costs

- The cost of shearing sheep should be included as an expense and not deducted from the sales price.

- Shearing costs are typically on a per head basis.

- If the sheep CAR estimate is for a flock, the shearing costs for rams should be included.

- Assumptions for estimating shearing costs should be summarized in a footnote or accompanying text.

Marketing Charges

- Commissions for handling the marketing of crops and livestock should be typical for the commodity.

- Any fees charged for using facilities necessary to the marketing process should be included.

- Grading charges for fruits and vegetables should be included.
- For some commodities, particularly livestock, there may be marketing charges associated with purchasing an animal.
- Assumptions for estimating marketing cost should be summarized in a footnote or accompanying text.

Cartons, Bags, and Tags

- Some commodities, particularly produce, require bags or cartons that must be purchased.
- These costs will be based on the amount of production.
- Assumptions for estimating any costs for cartons, bags, tags, and so forth should be summarized in a footnote or accompanying text.

Involuntary Checkoffs

- Involuntary checkoffs should not be deducted from the sales price. Rather, they should be listed as a cost of production.
- Assumptions for estimating checkoff charges should be summarized in a footnote or accompanying text.

Marketing Order Assessments

- Assumptions for estimating marketing order assessments should be summarized in a footnote or accompanying text.

Permits and Quotas

- Assumptions for estimating permit and quota charges should be summarized in a footnote or accompanying text.

Crop Insurance

- Include crop insurance cost only if expected income is adjusted to reflect reduced variability associated with the purchase of crop insurance. The impact of indemnity payments on revenue can be included either by adjusting the yield or by including a line for the expected indemnity payment.

- Crop insurance can be either for a particular hazard to production or for all possible threats to production.

- Managers can choose the level of coverage appropriate to their situation.

- Assumptions on coverage levels, impacts on income levels, and cost estimation procedures should be summarized in a footnote or accompanying text.